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Torquing Forces Coincident to Archwire Dimension and Composition in the Straight Wire Appliance

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TORQUING FORCES COINCIDENT TO ARCHWIRE DIMENSION AND COMPOSITION IN THE STRAIGHT WIRE APPLIANCE

By

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DEDICATION

To my wife, Joan

For her love, devotion and patience.

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My sincere appreciation is extended to all those who have aided in making this investigation possible. I would like to extend a special thank you to the following persons:

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The most profound gratitude I can express goes to my parents for offering the greatest support and encouragement through my first twenty-seven years of life and making me what I am.

AUTOBIOGRAPHY

John Katsis, Jr., was born on January 1, 1952, in St. Cloud, Minnesota, the son of John and Mary Eileen Katsis. He was the first of six children, having four brothers and one sister. In 1955, his family moved to the southwest side of Chicago and then two years later moved to Riverside, Illinois. He graduated from Riverside-Brookfield High School in 1969, and attended University of Illinois in Chicago. After four years, he graduated with a Bachelor of Science degree in 1973. In the fall he maticulated at University of Illinois College of Dentistry. A degree of Doctor of Dental Surgery was received in June, 1977 and the following July, he enrolled at the Graduate School of Dentistry, and in the Postgraduate program in Oral Biology. In May of 1978 the author was married to Joan Ellen Syz.

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CHAPTER I

INTRODUCTION

In the orthodontic treatment of malocclusion, it is desirable to direct forces to the dentition so as to align the teeth in a stable, functional and esthetic occlusal relationship. The edgewise appliance most commonly used by orthodontists today was designed to deliver forces to the teeth when the archwires are engaged in the brackets. Forces are dependent upon the size of the wire, stiffness, design and size of any loops, and degree of deflection of the wire. There are optimum forces to move teeth efficiently. Storey and Smith (1952) describe forces within a biologically efficient range as considered best for rapid tooth movement with reduced tissue and root destruction.

After orthodontically moving anterior teeth, the roots must be positioned to direct the forces of occlusion along the long axis of the teeth according to Jarabek (1963). This involves applying a torquing force to the roots to move the root through the bone. Rectangular archwires are tied into the rectangular slot on the edgewise bracket. The force exerted by the rectangular archwire in the slot depends on the torque in bracket, and the torque, stiffness and size of the archwire.

A simulated model of a maxillary dental arch was constructed. The size of the arch was developed to closely match the size of preformed maxillary rectangular archwires. Electronic strain guages were attached to the anterior teeth to measure the torquing force applied to the teeth with various archwire - bracket torque combinations.

Commonly used sizes of stainless steel and nitinol rectangular archwires were studied. Each archwire was inserted five times into three different bracket torque combinations. The resultant forces on the central and lateral incisor teeth were statistically analyzed comparing archwire size and bracket torque angulations for force produced.

It was the purpose of the following investigation to study the magnitude of torquing force produced by the straight wire edgewise orthodontic appliance. This would include varying the degree of bracket torque and the size and composition of the archwire and relate this to forces considered biologically efficient.

CHAPTER II

LITERATURE REVIEW

A. History of the Edgewise Appliance

The edgewise appliance most commonly used in orthodontics today was the invention of Edward H. Angle (1929). Although the modern appliance is strikenly different, the basic design is very similar. The edgewise appliance derived its name from the use of rectangular archwires placed edgewise in the rectangular slot on the bracket. The original use involved placing twists and bends in the archwire, which, when tied in the brackets, placed forces on the dentition to create the desired movements. The elastic stresses placed in the deformed archwire as it is engaged in the brackets provided the force of tooth movement. Forces of compression, tension, shearing, torsion and bending each stress the archwire. After Angle's death in 1930 the appliance design changed very little. The changes that did occur proceeded in many different academic directions with no real unity until recently.

Thurow (1975) described the original bracket design as 50 mils wide and now known as the narrow design. The first new size introduced after a few years was the 100 mils wide bracket. The next step was soldering two narrow brackets in exact alignment, on the band. These were the precursors of today's multiple brackets that are milled as a single unit on a common base. These brackets, vary from about 80 to 180 mils in width. The advantage of the wider dimension lies in greater control over rotations and root position. However, with increased bracket width, there is a decrease in the interbracket distance. For any given interbracket discrepency the forces applied by an archwire will increase with a decrease in interbracket width.

Edgewise orthodontic therapy today has evolved further, by varying the design of the appliance. Rather than tip, torque and in/out bonds in the archwire, these variations were built into the slot. It was Andrews (1976) who was first credited with incorporating three dimensional control into the design of the appliance. The straight wire appliance as he had coined it, was conceived by first studying ideal occlusions. Then fabricated by cutting slots into the brackets so a rectangular wire bent to the proper arch form lied passively in the slots, when the teeth were in ideal occlusion. Tip, torque, and in/out were incorporated into the bracket slots. This latest of appliance design relieved the orthodontist of bending the complex archwire configurations required to treat a patient. Bending the archwire was still required but not nearly to the same extent.

When archwires were tied into the edgewise appliance, forces were distributed to the brackets in a complex manner. Burstone (1976) attempted to describe the force system which was produced when a straight wire was placed in a non-aligned bracket system. He stated the force systems delivered from commonly used orthodontic appliances were relatively unknown. Attempts to determine the force used to seat the archwire in the bracket measured with force guages was highly inaccurate. Burstone further believed this was due to unknowns using the laws of statics. With the complexity of force systems applied to the dentition from a straight arch wire it was difficult to preduct the biologic response and the nature of the tooth movement expected.

B. Torque in Orthodontics

One of the greatest advantages of the edgewise appliance is the ability to torque the root of the tooth through bone. Torque is described as a movement of force or force couple applied to the root of a tooth in such a way so as to cause it to rotate around the central axis of the archwire. Jarabek (1963) described the action of the torquing force as always perpendicular to the radius arc and decreased as the distance from the archwire increased. The amount of work done by the wire may be calculated by use of the formula Work = Force X Distance. In the case of an arch wire engaged in the bracket where the force decreased as the work was done by the arch wire, the expression to calculate work would be as follows:

$$\text{WORK} = \pi r \int_{\theta_2}^{\theta_1} F_\theta \, \theta \, d\theta$$

In orthodontics, the principle use for a rectangular wire stressed in torsion is the lingual movement of the maxillary incisor roots. These are not the only teeth for which it is used, but these are most commonly torqued. The incisor roots are torqued to position the forces of occlusion along the long axis of the teeth. This will prevent a rabbited appearance and provide for overbite stability and an acceptable incisal guidance.

Edgewise torque has the advantage of close tolerances and a precision appliance. Application of forces from either a square or rectangular wire has a disadvantage because it has a narrow range of motion. After the teeth have rotated a few degrees the couple relaxes and become inactive.

The torquing force applied to the incisors has complex interactions throughout the dentition. As early as 1932, Brodie recognized the difficulty in controlling torque. "There is no mechanical principle in orthodontia so difficult to grasp as torque and it should be studied diligently before it is placed in operation on a patient. Its effectiveness will depend on the operator's knowledge of tissue reaction to various kinds of force and under this heading I would reiterate the cardinal principles that govern its action:

1. If the archwire is held so that its axis cannot shift the result will be root movement in the opposite direction.

2. If the archwire is encouraged to travel with the teeth,

they will tip with the apex as a pivot.

3. Torque force becomes elevation or depression when it travels into another plane of space.

4. In the newest mechanism, with all the teeth banded, torque force on one tooth will result in an opposite torque force on the next tooth if it is in the same line."

Schrody (1974) described the complex reaction that occurred when a rectangular arch was placed in the edgewise bracket. He observed the buccal segment reaction to anterior root torque. Using a tension guage to measure forces, he found a complex system of counter torque, buccolingual linear, and occlusogingival linear forces occurred. In the case of active anterior lingual root torque, an intrusive force was placed on the buccal segment teeth. This force was as high as a mean of 287 gm as an initial loading force on the canine with 25° active anterior torque in an .025 x .028 archwire. All of the wire measured demonstrated contractile forces in the canine region and expansion in the premolar and molar region.

Neuger (1967) measured the moments of torque applied to maxillary anterior teeth with light-wire torquing auxilliarys. These moments were found to change in magnitude with various changes in configuration of the torquing auxillary. It was found the forces produced various inversely with the size of the circle of the auxillary. Torquing auxillaries with spurs at zero degrees produced the highest forces on each of the teeth. Forces were found to become progressively less as the roots of the anterior teeth moved lingually.

Drecker (1956) used mathematical expressions to calculate forces and torques brought to bear against teeth by an archwire containing second order bends. The torques created were balanced by a couple. This couple intruded teeth at one end of the segment and extended them at the other end. The direction of the couple was opposite to the torque.

One problem in calculating the amount of torque applied with a rectangular wire is the discrepency between wire size and slot size. Jarabek (1963) discussed the amount of rotation of rectangular arch that must occur before the wire engaged the walls of the bracket. The two diagonally opposite points of the wire must contact the inner surfaces of the slot before force was applied. It was by this two point contact that the rectangular wire transmitted torque to the bracket. As the size of the archwire was decreased or as the angle between the slot and wire decreased. When a rectangular wire engaged the walls of the slot with a certain amount of force, stress was placed within the archwire so that it was in torsion. The stress that was placed on the archwire was distributed unevenly in the rectangular-wire while a round wire distributed the stress more evenly, when examined in cross section.

Thurow (1972) described torque control with rectangular wire as the only movement that required close engagement of wire and bracket slot. A .001 inch freedom of the wire in the slot gave 2° to 4° of rotation before engaging the walls of the slot. A difference of .002 inch brought this rotational freedom to well over 5°. It was therefore advocated rectangular archwires used for torque control be kept within .002 inch of the slot size. Wires that fit the slot too precisely should never be used to torque individual teeth, however. In this case the wire should be sufficiently undersized to permit free reverse movement equal to any active torque action that was being applied to an adjacent tooth.

Dental arch form is important in positioning the teeth in balance with the occlusion and musculature. Brader (1972) described dental arch form in which the teeth assumed unique positions along a compound curve representing an equilibrium at all points and limited by the counter balancing forces of the tongue and the circumoral tissues. The geometry of the dental arch was best approximated by a closed curve with the curvilinear properties inherent of the trifocal ellipse with the teeth occupying a portion of the curve at its constricted end. Treatment objectives should be to position the teeth in balance with both the musculature and the forces of occlusion.

C. Physiologic Tooth Movement

The periodontium undergoes changes during orthodontic tooth movement. The periodontal ligament, cells, capillaries, nerves and alveolar bone are all affected by the orthodontic force. Reitan (1964) discussed the fundamental process of tooth movement in which certain general principles can be applied. Alveolar bone was resorbed whenever there was compression of the periodontal membrane. The stretching and compression of the fibers of the periodontal ligaments were converted to apposition and resorption. The complicating factors occurred on those relatively simple principles with variations in magnitude, direction and duration of force. Other variables included age, sex, pregnancy, alveolar bone types and unknown individual differences.

In considering the many variations that may affect orthodontic tooth movement, ideally one would like to eliminate destructive factors and maximize beneficial factors. Factors such as force magnitude and duration are especially relevant. The concept of optimal force apparently developed when such men as Oppenheim (1911) and Schwartz (1932) assumed the periodontal ligament was similar to a hydrostatic system maintained by the blood pressure of the capillary bed. A force above the capillary pressure of 26 grams per square centimeter was thought to strangulate the periodontal tissues, causing tissue necrosis, or even force the tooth into physical contact, with the bone.

Storey (1973) divided tooth movement within the bony socket and tooth translation through bone into three different biologic systems, (1) bioelastic, (2) bioplastic and, (3) biodisruptive deformation of tissues. Bioelastic deformation occurred with the rapidly oscillating forces of occlusion. The interstitial fluid acted as a lubricating film. The architecture of the periodontal ligament induced exogenous circoid aneurysms by tightening randomly orientated fibers interlacing the small blood vessels and the viscoelastic properties of the ligament that demonstrated great resistance to a heavy instaneous force. But the ligament was easily compressed with light forces of long duration. The bioelastic deformation occurred under the rapidly changing forces of occlusion while the bioplastic changes occurred under a continuous force. If forces were excessive the biodisruptive process occurred. Along with interruption of nutrition, ischemia and cell death, the inflammatory process occurred. There may also be rupture of connective tissue. During adaptation and repair of the biodisruptive process, cellular processes were still carried out but at a lower level of efficiency. The bony remodeling that must occur for tooth movement was slowed. With this biologic system of cellular response in mind, it can be seen how the idea of optimal force developed.

The initial research of Storey and Smith (1952) on humans involved distal tipping of cuspids with springs following extraction of first bicuspids. Light forces of 175-300 gms were used on some of the canines and on the others, heavy forces of 400-600 gms were used. They concluded there was an optimal range of pressure on the tooth-bone interface which produced maximum tooth movement. Heavy pressures caused undermining resorption and movement of anchorage dental units. The optimal force range they calculated was between 150-250 gm (5-9 oz) for distal tipping of cuspids. Other researchers have reported on optimal force systems. Burstone and Groves (1960) retracted anterior teeth by simple tipping and observed optimal forces of 50-75 gms of force. And Reitan (1957) stated the maximum force needed during any stage of continuous bodily movement of canines was approximately 250 gms.

In a radiographic study Storey (1953) evaluated changes in the lamina dura with various magnitudes of force. A tooth with a light force reacted so behind the newly formed bone on the tension side developed an area of resorption where spongy bone was formed. Ahead of the area of resorption on the pressure side, an area of deposition occurred where lamina dura was reformed. Storey described the moving tooth as having four recognizable zones of activity while being moved with a light force. On the pressure side resorption occurred, then deposition, and on the tension side, deposition then resorption.

With forces in excess of the optimal range a process of "undermining resorption" occurred on the pressure side. Movement of the tooth practically ceased until boney remodeling from the spongy bone occurs. Storey (1973) felt there was a significant difference in the appearance of bone laid down on the tension side following the application of different degrees of force. With light forces the bone was dense and the trabeculae oriented in the direction of the applied force, with heavy forces the bone laid down was less dense and could be differentiated from the lamina dura while the trabeculae were not oriented in the direction of the applied force.

Not all researchers agreed with the optimal force theory. Hixon et. al. (1969) experimenting with the bodily movement of cuspids achieved different results and postulated higher forces per unit area increased the rate of biologic response. They also felt the results of Storey and Smith (1952) were misleading due to the tipping movement used and maximum pressures placed on the alveolar crest.

Boester and Johnston (1974) again studying cuspid retraction found a light two ounce force level produced significantly less cuspid movement than five, eight and eleven ounces. There was no significant difference between five, eight and eleven ounces, with anchorage loss independent of the force used. Patient discomfort also was found to be independent of the force used.

Andreasen and Johnson (1967) used unilateral headgear to asymetrically distribute forces to the maxillary molars on sixteen young orthodontic patients. With 200 gms. and 400 gms. applied to the maxillary molars, they found the heavier forces moved the molars further and at a higher rate of speed then did the lighter force.

Reitan (1950) studied the effects of force magnitudes on different alveolar bone types. First he found there were histologic variations in the bone density surrounding 54 teeth in the 11 - 12 year old persons studied. Then using dogs and applying orthodontic force to the teeth it was found the degree of movement depended upon the density of the alveolar bone. If the continuous torquing force applied to the teeth was excessively large, extensive root resorption occurred even if the bone was moderately dense.

Reitan was not alone in noticing the effect of excessive force on the dentition. Jarabek (1963) referred to root resorption as the scar of an orthodontic operation. The causes of root resorption were multifactorial but there were some which one directly related to orthodontics. These include: (1) duration of forces, (2) kind of forces, meaning continuous or intermittent, (3) magnitude and, (4) appliance rigidity. Of those he considered force magnitude to be the most significant.

D. Electronic Measuring Devices

The accurate measurement of forces acting on the dental arch has been attempted by many researchers. Feldstein (1950) used hydrolics in a technique to measure the immediate forces on the buccal or lingual surface of a tooth. Chaconas et. al. (1974) used load cells to measure the effect of wire size, loop configuration and gabling on canine-retraction springs. And Vanderby et. al. (1977) used angular displacement transducers and a linear variable differential transformer to measure force systems from vertically activated orthodontic loops. These were all attempts to quanitify the forces placed on the dentition.

Electronic strain guage technology has been used by researchers in measuring oral forces. Alderisio and Lahr (1953) recorded the myodynamic forces of the lip, cheek and tongue on the dentition with strain guages. Lazzara (1976) used strain guages attached to the Goshgarian palatal bar and measured lingual forces that occurred on swallowing. And Winders (1956) attempted to measure forces exerted on the dentition by the perioral and lingual musculature during rest and function. He measured five areas of the dentition at rest and during swallowing. This was accomplished using strain guage technology.

Strain guages work on the principle of measuring the changes in electrical resistance as the cross sectional area of a conductor changes. Penny and Lissner (1955) described the basic principles of strain guage measurement. Strain was a fundamental engineering phenomenon that was present in all matter either due to a load applied to a body or the weight of the body itself. When an electrical current passed through a conductor the electrical resistance varied as a function of the strain present in the conductor. This principle was applied when developing the small grid of foil on the guage. The foil grid was etched on a flexible polyimide backing. The grid was then soldered or glued to the object that was to be stressed. When the grid was stretched or compressed the resistance changed.

The electrical circuit of the wheatstone bridge had four wide arms with three known resistance values that permitted finding of the unknown fourth. The fourth resistance arm was the foil strain guage. In this technique, the ratio arms were balanced one to one and the known resistance of the third was varied to equal the unknown resistance in the foil guage. In this way the strain applied to the object being analyzed can be measured. Perry and Lissner (1955) described the constant of proportionality between stress and strain known as the modulus of elasticity of the material or Hooke's law. And when stress was plotted verses strain a linear relationship existed where the slope was a constant and known as Young's modulus.

E. Free-Body Analysis

The basic idea of free body analysis according to Thurow (1972) stated there existed a static system of forces in the orthodontic appliance and associated teeth. All forces must be in balance. In this system there was no movement other than tooth movement, or slow physiologic changes, so that at any given time the entire complex can be considered to be in a state of static equilibrium. If there were any unbalanced force in this system, something would move in response to it. The fact that nothing moved proved all forces were in balance, and this made it possible to determine what forces were at work and in what direction they were operating. The basic requirement for static analysis was there must be no movement within the system.

Thurow (1972) described balanced linear forces and moments within the orthodontic appliance. All straight line (linear) forces must be balanced by equal and opposite forces. In mathematical terms, the algebraic sum of the linear forces must be zero. All moments around any point must also be in balance. Moments were measured by the product of force times its distance from the fulcrum. This dimension was called the moment arm. Moments were identified by the units of force and distance that are used to measure them. An example of this would be footpounds or gram-millimeters etc.

Measurements of the moment force according to Thurow (1972) must be made along a line at right angles to the moment arm. The moment arm was always the shortest distance from the center of rotation to the line of force, regardless of the point of application. When two equal forces were acting in opposite directions along parallel lines, those forces produced the same net moment around any point in the plane in which they were acting. Such a pair of forces was called a couple. The moment of a couple was measured by multiplying one of the forces of the couple by the distance separating the forces.

Thurow (1972) considered a static free-body system as satisfying in the following conditions:

1. The part under study must be clearly delineated. There were no limitations on the selections, size or complexity of the free body.

2. All forces acting at the "cut surfaces" that isolate the free body must be identified. Force values must be known or assured for enough of these forces to make it possible to determine the others.

3. There can be no movement of the free body in relation to the immediate environment. This was a static analysis and did not consider the effects of inertia, acceleration, or velocity that were associated with movement.

4. All linear forces acting on the free body must be in balance. Each force must be countered by an equal and opposite force or combination of forces.

5. All moments around any point must be balanced by equal and opposite moments or combinations of moments.

CHAPTER III

MATERIALS AND METHODS

I. Selection of Appliance:

The selection of the appliance was performed by chosing one of the most commonly used edgewise appliance in orthodontic treatment today. It was selected to provide some guidelines to clinicians and future researchers. The basic design of Unitek's Twin Torque appliance was very similar if not identical to the patent of Andrews (1976). The Twin Torque Appliance was commonly used and/or preferred by the faculty at Loyola Orthodontic department. The slot torque arrangement of the Twin Torque Appliance possessed the greatest amount of variation compared to other manufacturers. Torque combinations were acquired in three commonly used angulations in the .022 x .028 slot. The rectangular archwires were selected for those used commonly in orthodontic treatment. Unitek stainless steel maxillary preformed archwires tested were of the following dimensions: .016 x .022, .017 x .025, .018 x .022, .019 x .025 and .021 x .025. The anterior bracket torque combinations were 8° on the lateral incisor, 12° on the central incisor; 13° on the lateral incisor and 17° on the central incisor; and finally 15° on the lateral incisor and 25° on the central incisor. (Figure 1.)

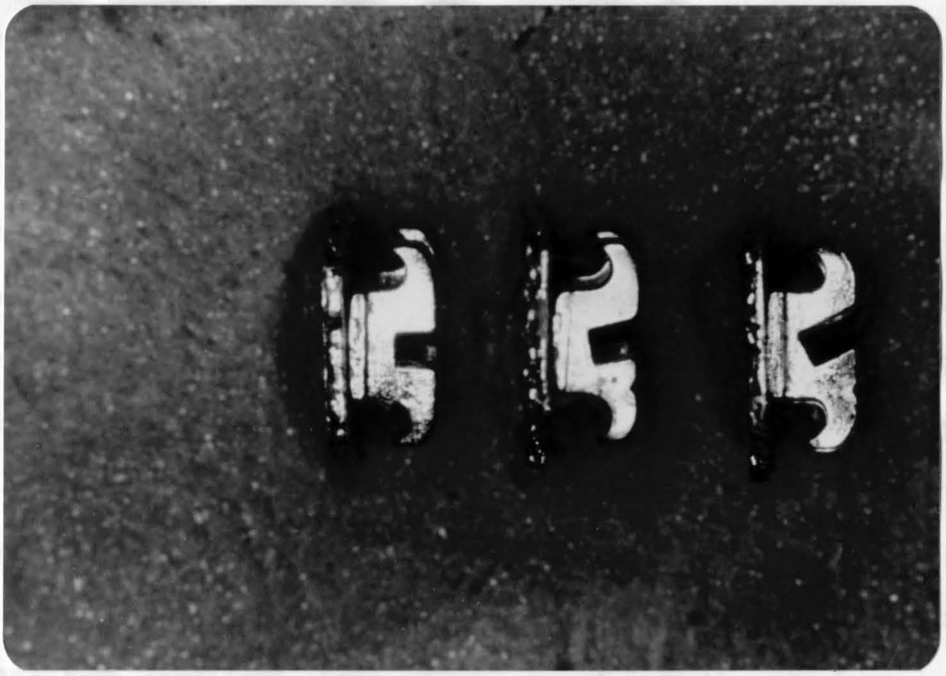


Figure 1. Lateral View of Torqued Anterior Brackets.

II. <u>Fabrication of the Measuring Devices</u>:

The specific purpose of the study was to measure the effective torquing force applied to the maxillary incisors with the straight-wire appliance when archwires of different sizes and composition were inserted into different torqued brackets.

An electronic device was designed, and fabricated to simulate the maxillary dentition. Dentiform teeth were positioned in a wax form in an average arch width so that commonly used preformed archwires would lie passively in brackets attached to those teeth without expansion or contraction of the archwire. The four incisor teeth were removed and substituted with four cold cured acrylic crowns of average size. Stainless steel .045 inch round wires were used as roots and embedded in the wax. (This was considered an accurate mechanical simulation of an average maxillary dentition.) The four acrylic incisors were removed from the wax form and it was processed in heat cared acrylic to provide a stable base for the mechanical simulation. (Figure 2.)

Precision foil strain guages, PA-06-015EE-120, manufactured by Magnaflux Corporation of Chicago were used in this study. The dimensions of the miniature guage were .015 inches in length and .020 in width. Normal thickness of the guage was .0009 $\pm$ .0002 inches. The guage was comprised of a stabilized constant etched foil grid mounted on a flexible polymide backing. The guage was capable of measuring strains up to $3^{o}/_{o}$ elongation with an accuracy

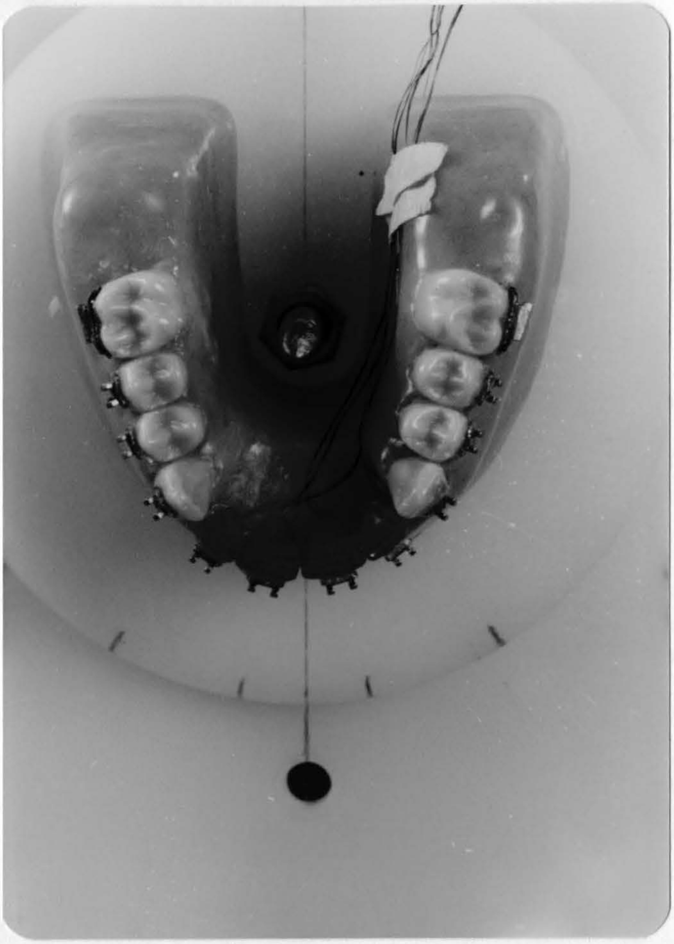


Figure 2. Occlusal View of Maxillary Arch Simulation.

of 5%. (Figures 3 & 4.)

After selection of the proper guages, the metal surfaces of the .045 inch stainless steel wires were cleansed with a neutralizer followed by methyethyl ketone. Guages were attached with Eastman 910 adhesive using finger pressure and a teflon strip to conform the guage to the surface of the wire. After the adhesive had sufficiently cured the excess adhesive was removed and the guages were wired into a wheatstone bridge with #39 polyurethane insulated magnetic wire.

Guages were wired, while the circuits and resistance of the bridge checked. If a slight variation in guage resistance existed between the two guages on either side of the .045 wire, pumice was used to change the resistance of one of the guages until they were in balance.

Guages were wired to a Magnaflux GB-100 switch and balance unit. Channels would be changed to allow each individual guage pair to be balanced. The switch and balance unit allowed measurement of each guage without rewiring, by selecting the proper channel for each tooth. The Magnaflux GA-100 strain indicator recorded the strain induced on the incisor teeth. (Figure 5.)

III. Calibration

Brackets were mounted on the acrylic anterior teeth with Eastman 910 adhesive. The brackets were first placed on a round

Figure 3. Strain Guage PA-06-01 5EE-120.

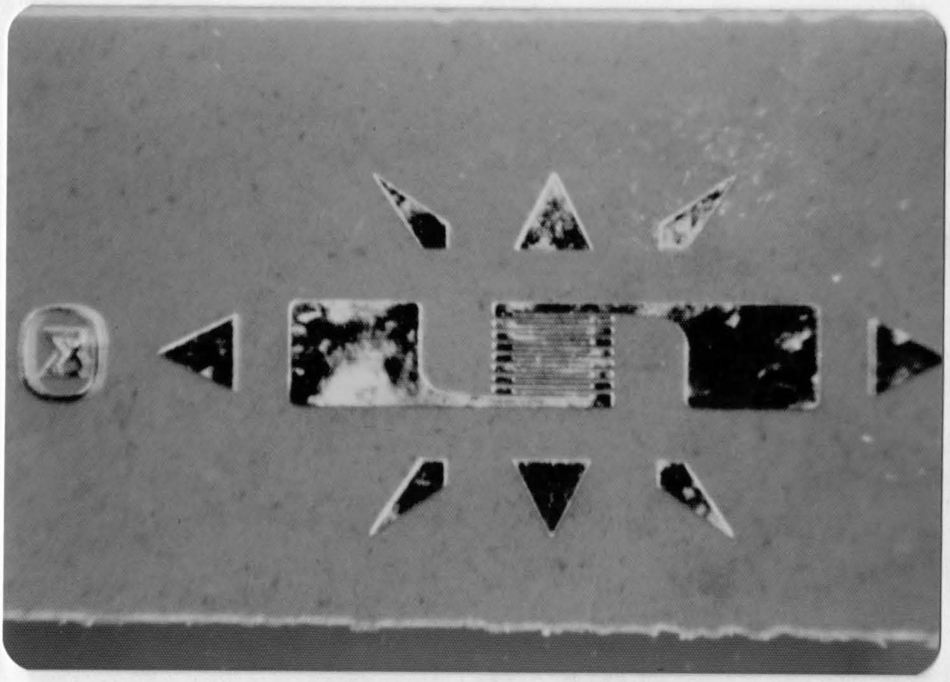


Figure 4. Center Section of Strain Guage.

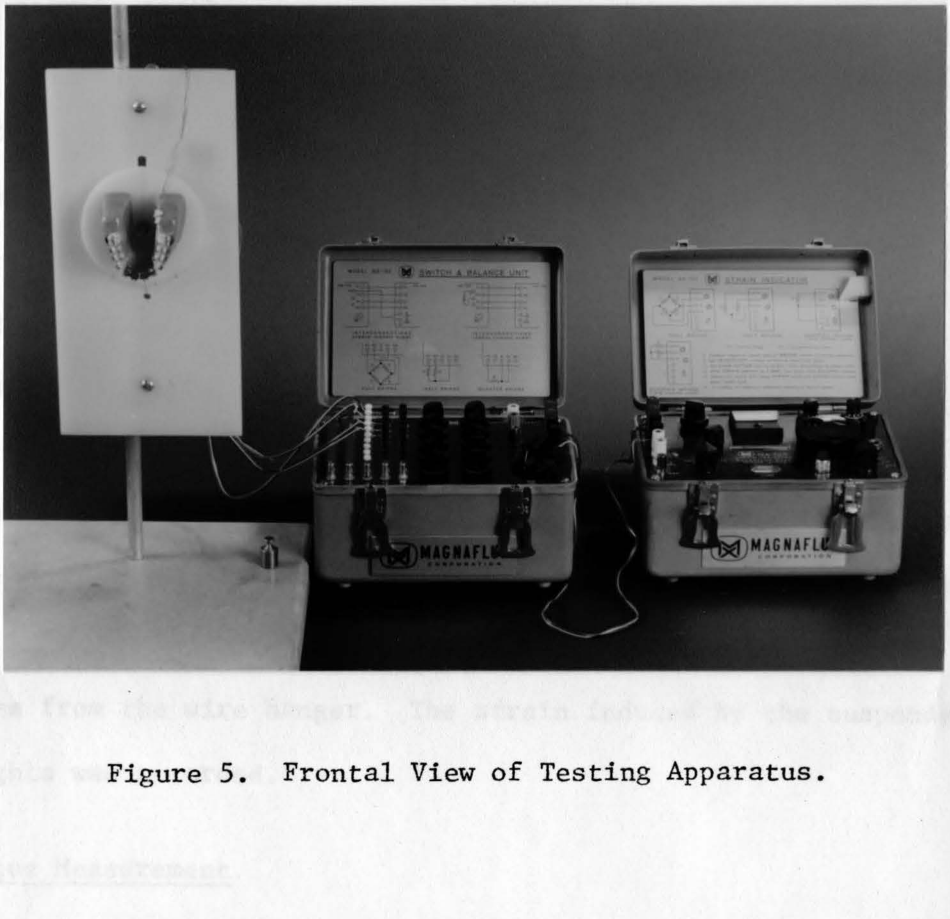


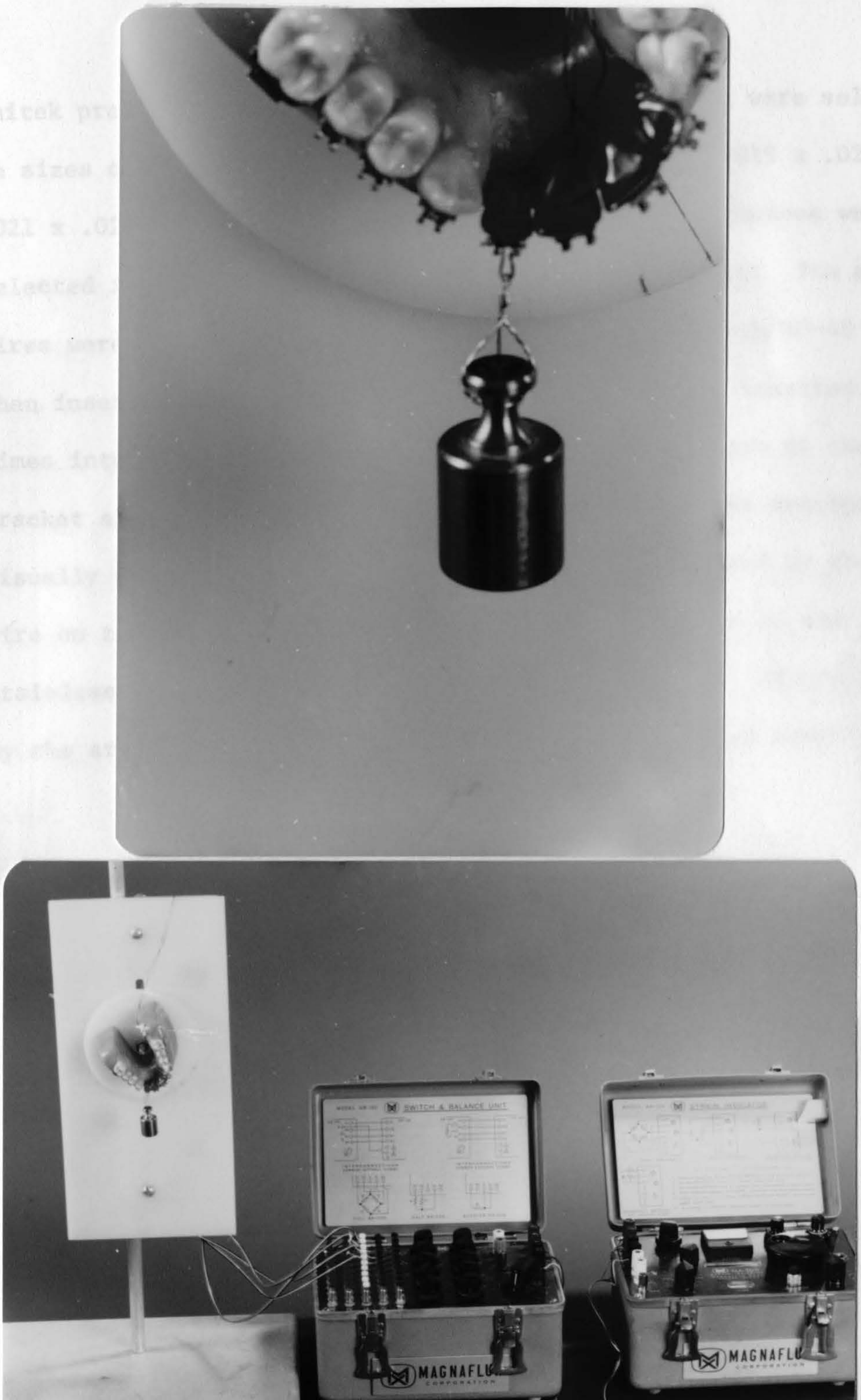
Figure 5. Frontal View of Testing Apparatus.

.022 stainless steel archwire and positioned in the center of the incisor crowns. The incisor crowns labial surface had previously been flattened perpendicular to the plane of occlusion. The bracket face was positioned so as to be perpendicular to the plane of the archwire. Adhesive was flowed between the mesh backing and the acrylic tooth.

Calibration of the appliance involved mounting the simulated maxillary dentition on a ringstand. The dental arch could be rotated to change the position of the teeth with respect to the floor. (See Figures 6 & 7.) The bracket face represents a tangent to the archwire. Torquing forces applied to the tooth by the archwire will be perpendicular to a tangent at bracket surface. To simulate the force applied to the tooth a weight was suspended from a hanger in the center of the bracket slot. The weight was hung so as to apply a force perpendicular to the archwire at that point, weights of one, two, three and four ounces were each hung five times from the wire hanger. The strain induced by the suspended weights was recorded.

IV. Torque Measurement

Unitek Twin Torque medium siamese anterior direct bond brackets were used in this study. Torque variations included 12° on the central incisors and 8° on the lateral incisors in one combination, 17° and 13° in another, and 25° and 15° in the third.



Figures 6 & 7. Calibration of Appliance with One Ounce Weight.

Unitek preformed maxillary stainless steel archwires were selected in sizes of .016 x .022, .017 x .025, .018 x .022, .019 x .025 and .021 x .025. Unitek performed maxillary nitinol archwires were selected in .016 x .022, .017 x .025, and .019 x .025. The archwires were first checked for symmetry, lubricated with WD-40 oil and then inserted into the brackets. Each archwire was inserted five times into the maxillary arch and pressed to the depth of the bracket slot. The marked midline on the archwire was matched visually to the dentiform midline. The forces induced by the archwire on the tooth expressed itself in the deflection of the .045 stainless steel wire supporting the incisor crowns. Strain induced by the archwire on the incisors was then measured and recorded.

CHAPTER IV

RESULTS

The following data was collected from testing archwires of five commonly used dimensions and measuring the force produced by three different bracket torque angulation combinations.

Table 1 depicts the means and standard deviations acquired in calibration of the incisors. The results for the one, two, three and four ounce weights are shown. The mean microstrain per ounce was calculated for each of the teeth. This was also calculated for each of the four weights used, and averaged. A conversion factor was derived to multiply microstain scores for each of the teeth into units of ounces.

Table 2 and 3 relate converted units for each of the archwires tested. Table 2 shows the torquing forces resultant of the stainless steel archwires tested and Table 3 shows nitinol archwire forces. Each archwire was placed five times and the strain induced by the archwire was recorded for each of the four teeth. In order to statistically analyze the results, the right and left central incisor scores were combined together to eliminate anticipated slight bracket variations and bracket mounting variations. The lateral incisors scores were also combined in this manner. The means and standard deviations are presented in their respective tables.

Table 1. Results of Calibration of Maxillary Anterior Teeth in Microstrain.

		Bracket No. 1	2	3	4
1 oz.	$\overline{X}_1$	200.8	200.6	178.6	207.6
	SD	1.9	1.9	.894	.548
2 oz.	$\overline{X}_2$	395.8	404.6	355.2	408.4
	SD	.4	1.6	1.64	.548
3 oz.	$\overline{X}_3$	595	601.2	528.6	608.6
	SD	.7	.447	1.14	.548
4 oz.	$\overline{X}_4$	810.6	805.6	706.8	796.6
	SD	1.6	3.286	1.30	4.775
	$\overline{X}_1/1$	200.8	200.6	178.6	207.6
	$\overline{X}_2/2$	197.9	202.3	177.6	204.2
	$\overline{X}_3/3$	198	200.4	176.2	202.9
	$\overline{X}_4/4$	202.65	201.4	176.7	199.2
	$(\overline{X}/oz.)/4$	199.84	201.2	177.3	203.48
	SD	2.3	.87	1.06	3.5

Table 2. Mean Force in Ounces Produced by Stainless Steel Archwire Trials on Bracket Torques Tested.

	12° Central Incisor	8° Lateral Incisor	17° Central Incisor	13° Lateral Incisor	25° Central Incisor	15° Lateral Incisor
.016 x .022	.0695 ±.0693	.0315 ±.0316	.1920 ±.1259	.0975 ±.0921	.2845 ±.1006	.1010 ±.0538
.017 x .025	.0480 ±.0508	.0795 ±.0515	.1525 ±.1450	.0470 ±.0542	1.009 ±.2017	.569 ±.2119
.018 x .022	.0775 ±.0380	.0925 ±.1026	.0675 ±.0625	.0245 ±.0315	1.433 ±.2230	.635 ±.3079
.019 x .025	.1640 ±.1152	.1065 ±.0576	1.063 ±.1792	.7470 ±.1990	4.311 ±.8174	2.062 ±.1860
.021 x .025	1.225 ±.3614	1.057 ±.2148	1.712 ±.477	1.212 ±.2848	4.950 ±1.539	2.775 ±.534

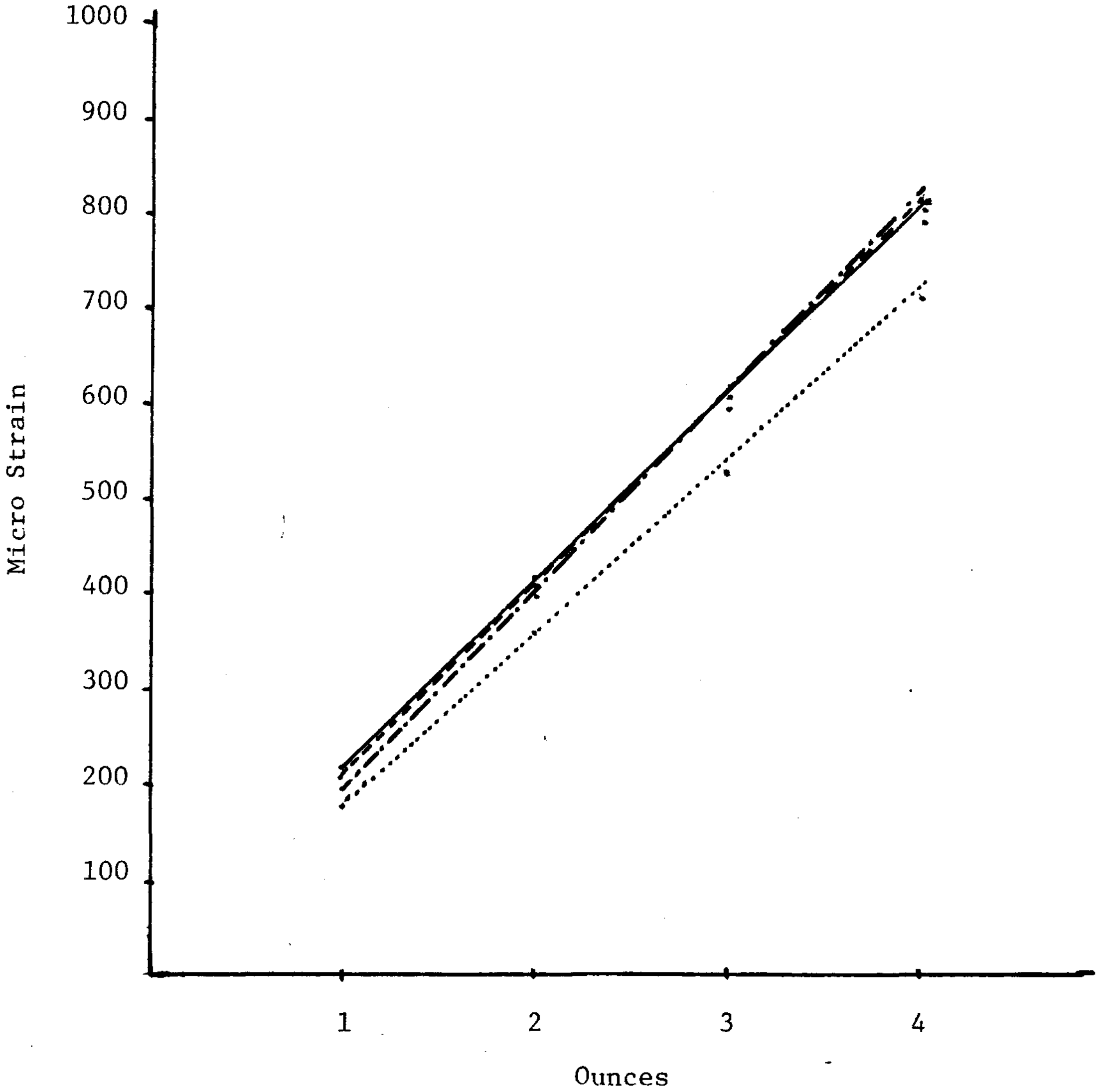
Figure 8 shows the plotted results of the calibration. The induced microstrain was plotted verses ounces of force applied to the center of the bracket slot. The graph shows the near linear relationship achieved by the calibration forces.

Figures 9, 10, 11, 12 and 13 were compiled to illustrate the effect on the incisors of various stainless steel archwire-bracket torque combinations. Each dimension of stainless steel archwire was compared for bracket torque verses force delivered. Torque force on the central incisors varied from a mean of .048 ounces on a 12° torqued bracket with a .017 x .025 stainless steel archwire to a mean of 4.95 ounces with .021 x .025 stainless steel archwire and 25° bracket torque. Lateral incisor torque force varied from a mean of .032 ounces on a 8° torqued bracket with an .016 x .022 stainless steel archwire to a mean of 2.72 ounces on a 15° torqued bracket and an .021 x .025 stainless steel archwire.

Nitinol archwires were compared in a similar manner. The results in Table 3 were plotted to illustrate the effect on the incisors of various nitinol archwire-bracket torque combinations. In Figures 14, 15, and 16 each size of nitinol archwire was compared for bracket torque verses torquing force. The forces produced were less than those produced by the same stainless steel archwires of a given dimension. Only in the highest of bracket torques and largest of rectangular archwires do torquing forces from nitinol archwires rise about .65 ounces.

To further examine the effect of archwire dimension on the force

Figure 8. Calibration of Maxillary Anterior Teeth.



1. Maxillary Left Lateral Incisor
x 2. Maxillary Left Central Incisor
3. Maxillary Right Central Incisor
4. Maxillary Right Lateral Incisor

Figure 9. Archwire Induced Torque by .016 x .022 Stainless Steel.

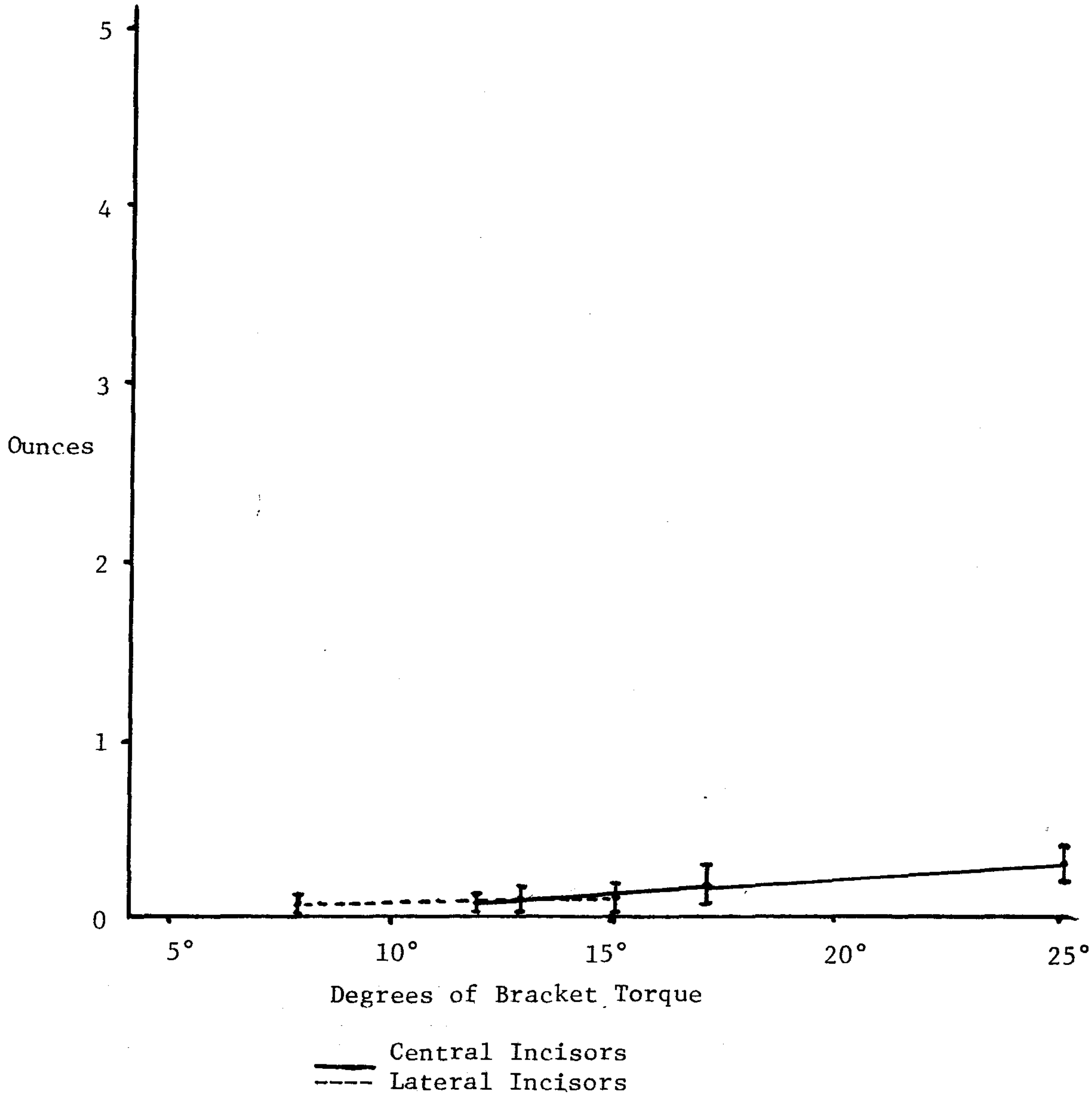


Figure 10. Archwire Induced Torque by .017 x .025 Stainless Steel.

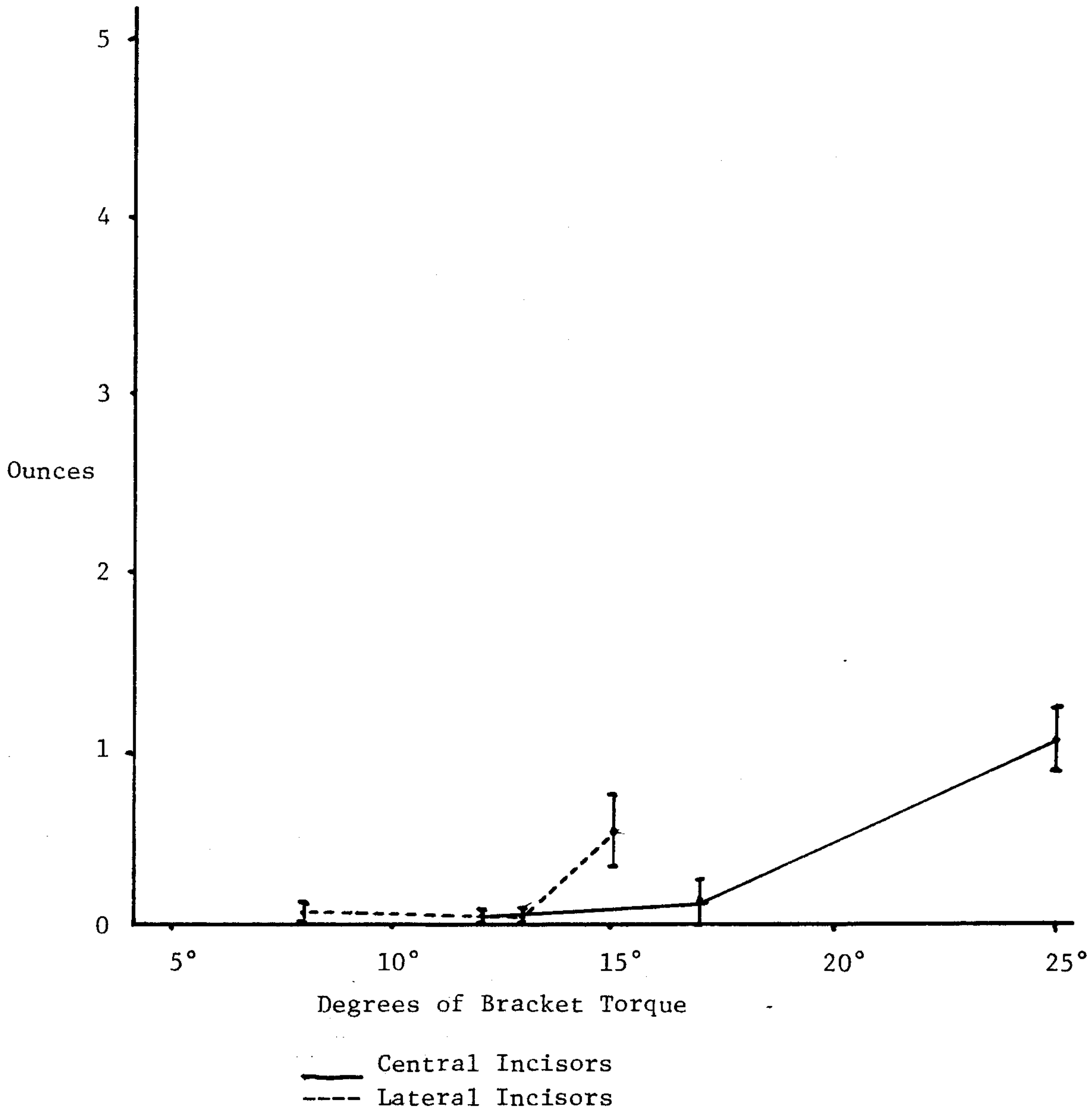


Figure 11. Archwire Induced Torque by .018 x .022 Stainless Steel.

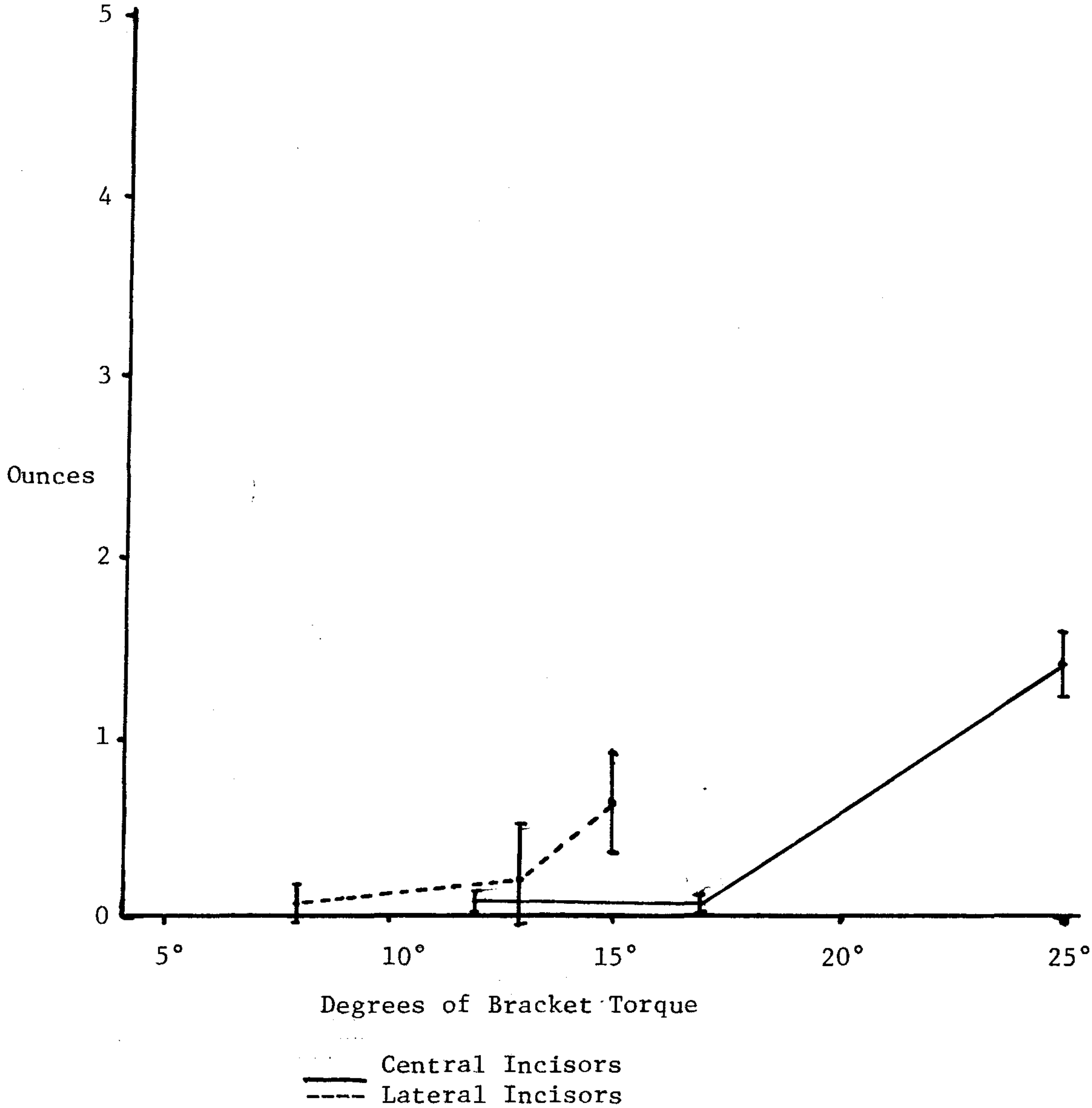


Figure 12. Archwire Induced Torque by .019 x .026 Stainless Steel.

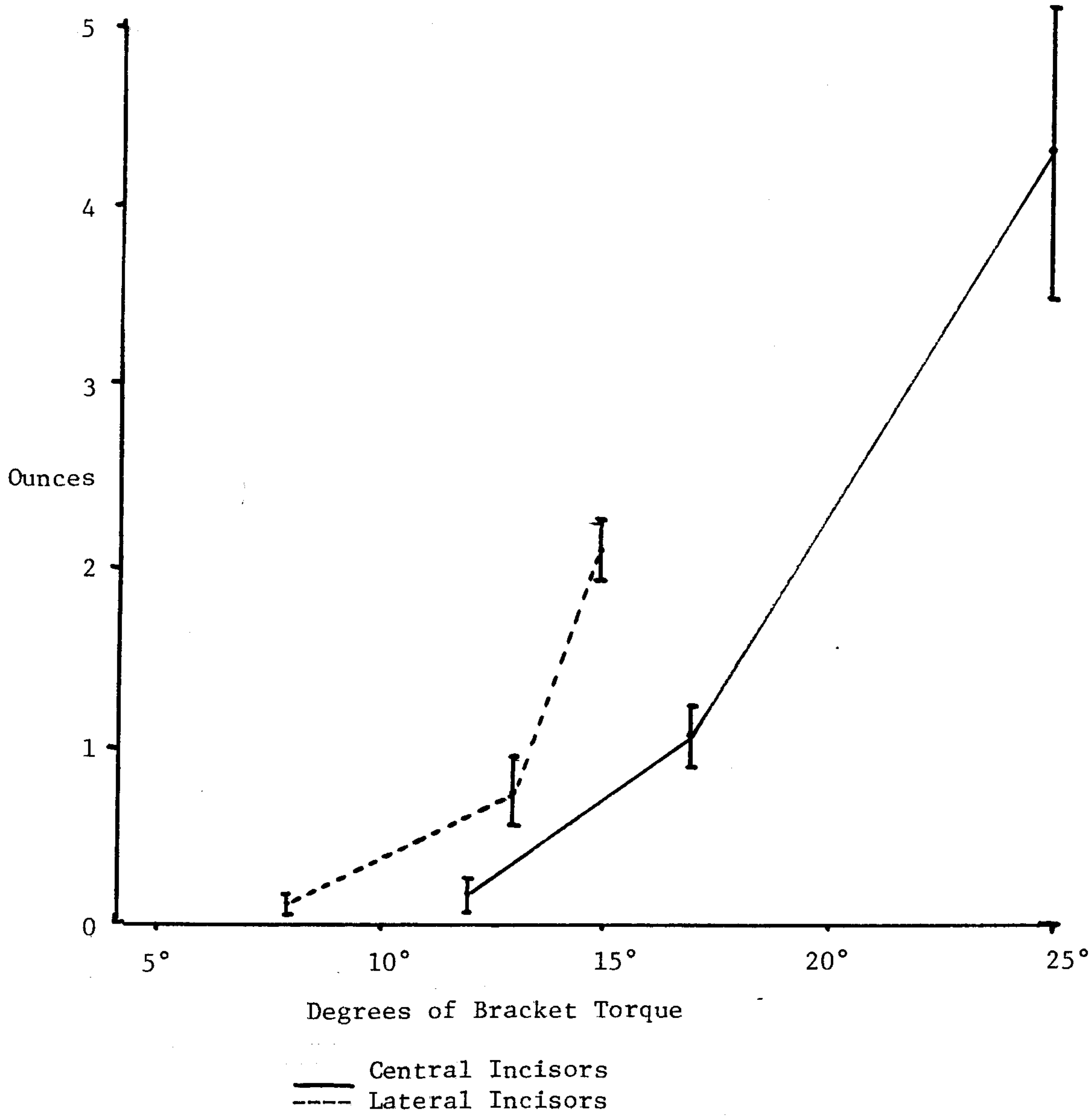


Figure 13. Archwire Induced Torque by .021 x .025 Stainless Steel

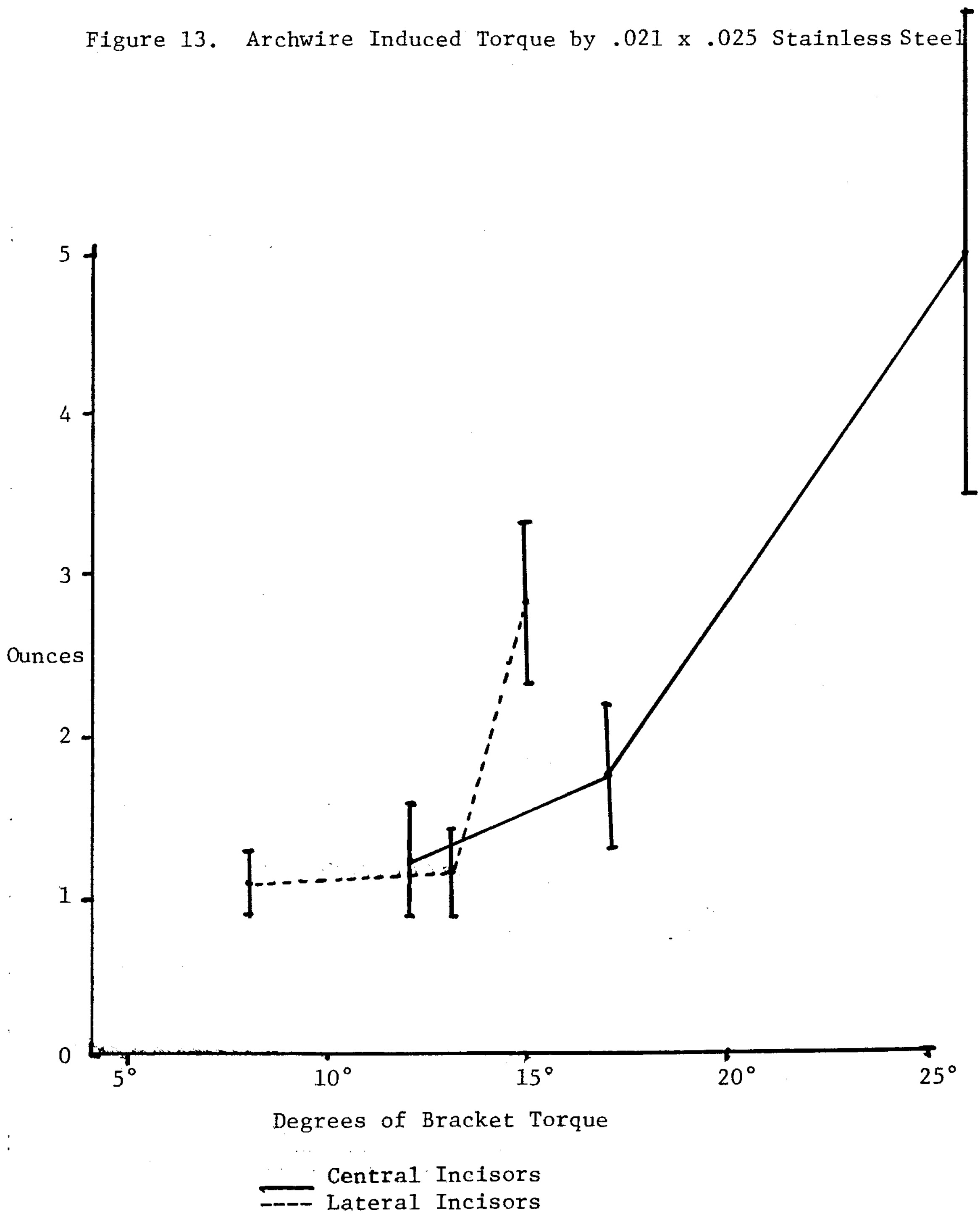


Table 3. Mean Force in Ounces Produced by Nitinol Archwire Trials on Bracket Torques Tested.

	12° Central Incisor	8° Lateral Incisor	17° Central Incisor	13° Lateral Incisor	25° Central Incisor	15° Lateral Incisor
.016 x .022	.0443 ±.0489	.0440 ±.0545	.0405 ±.0455	.0341 ±.0426	.1014 ±.1395	.0664 ±.0869
.017 x .025	.1470 ±.0220	.0969 ±.1300	.0585 ±.0486	.0488 ±.0409	.5865 ±.1712	.2375 ±.0533
.019 x .025	.0420 ±.0546	.0891 ±.0854	.0600 ±.0441	.0175 ±.0198	.6505 ±.0376	.2938 ±.0394

Figure 14. Archwire Induced Torque by .016 x .022 Nitinol.

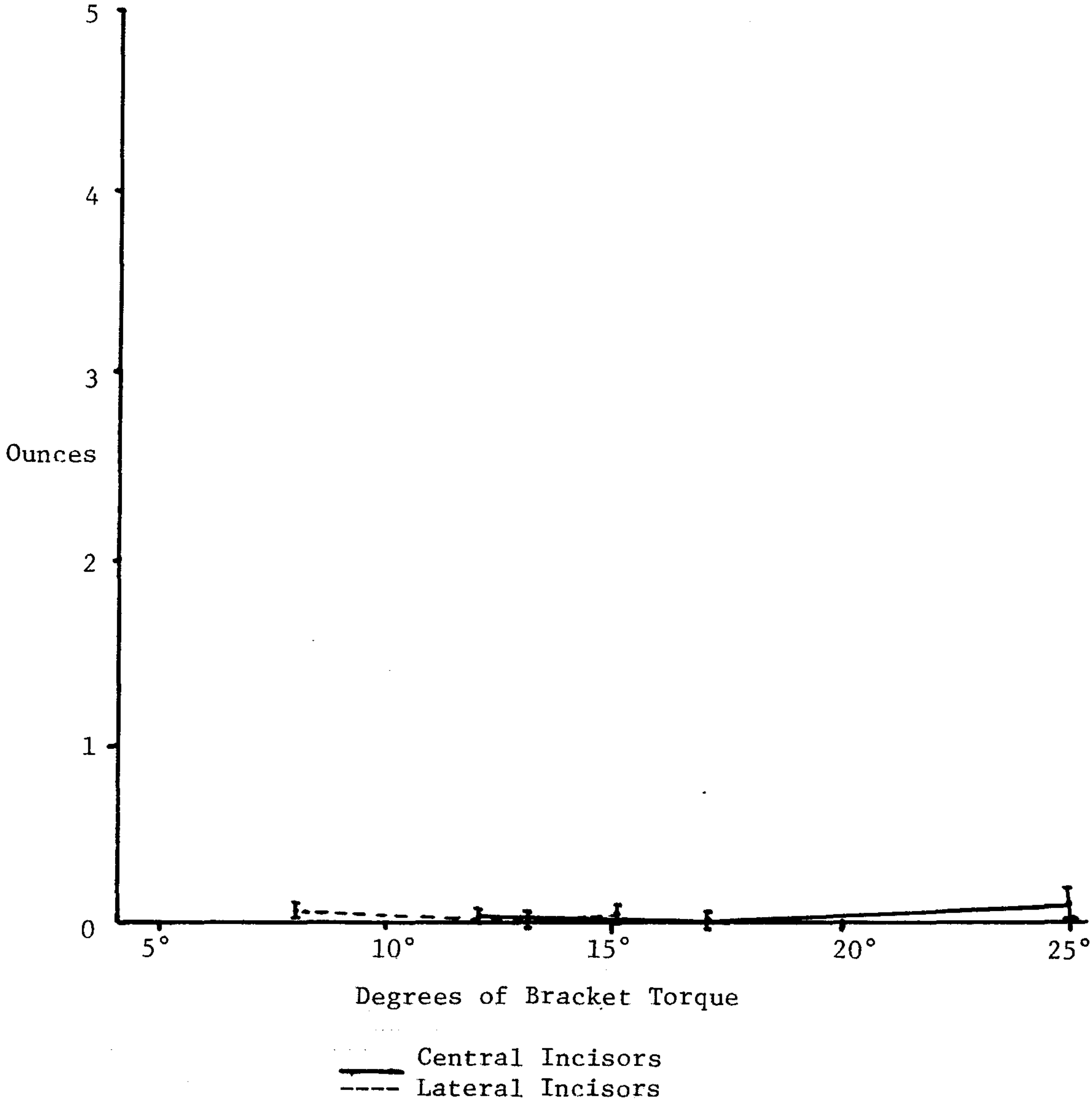


Figure 15. Archwire Induced Torque by .017 x .025 Nitinol.

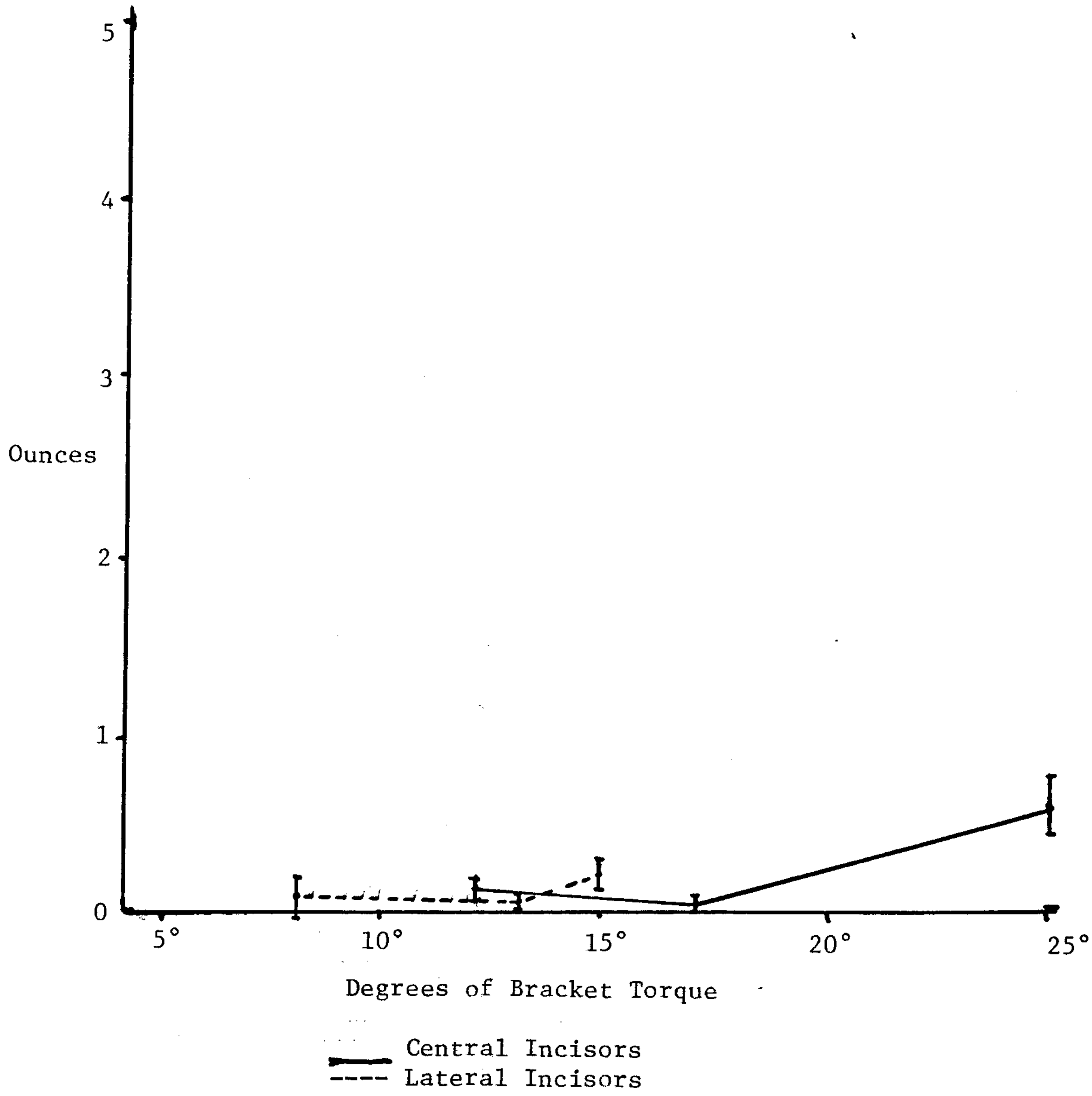
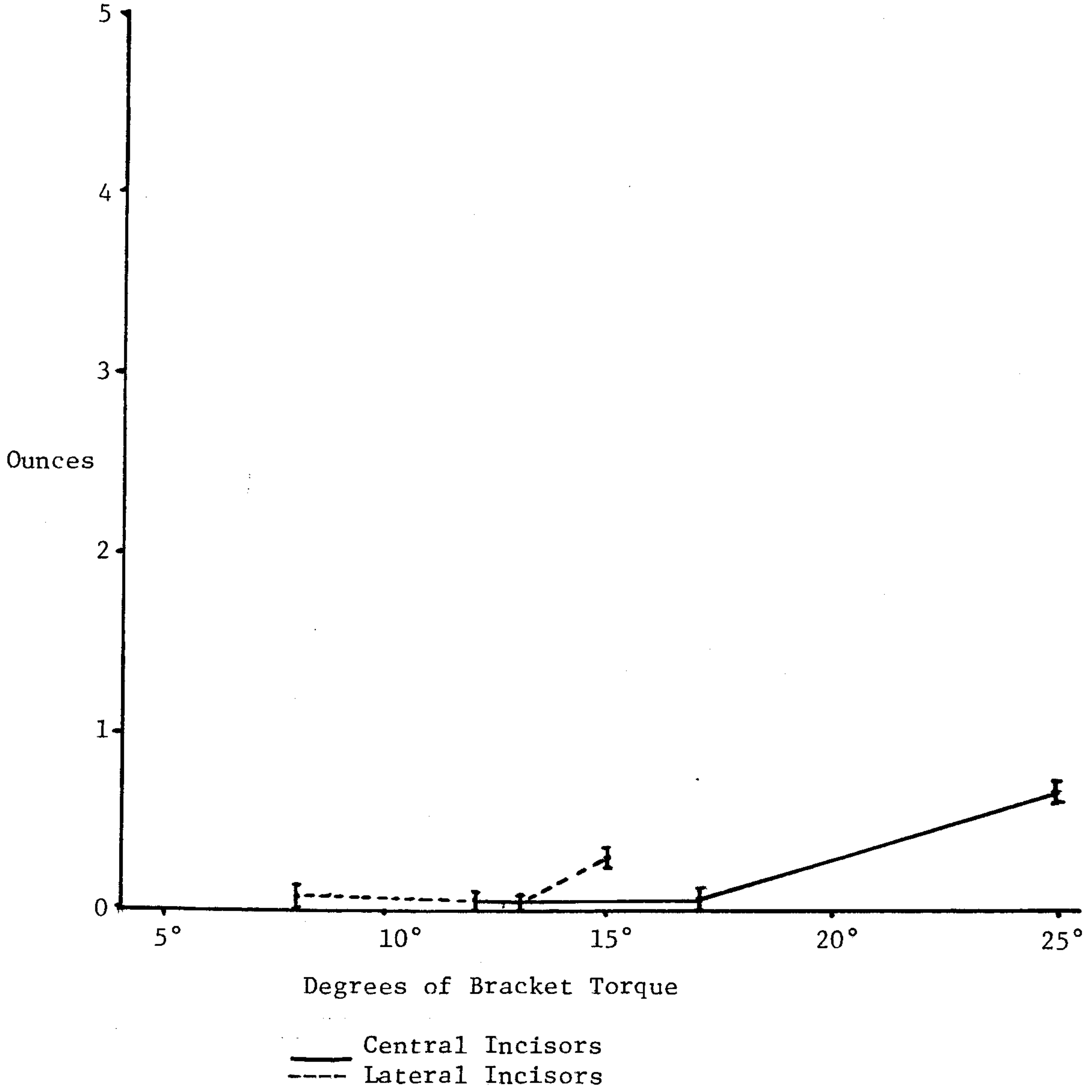


Figure 16. Archwire Induced Torque by .019 x .025 Nitinol.



produced, the cross-sectional diameter of the stainless steel archwires were compared to torquing force. Figure 17 shows the results for 12°, 17°, and 25° of bracket torque on the central incisors. Figure 18 comparatively looks at the effect on the lateral incisors with 8°, 13°, and 15° of bracket torque.

Table 4 shows the t scores and probabilities from a 2 sample t tests in comparing difference between stainless steel archwire dimension induced torque. Central and lateral incisors were both tested over the various bracket torques.

Table 5 relates t scores and probabilities from 2 sample t tests in comparing different bracket torques on the central and lateral incisors using stainless steel archwires.

Nitinol archwires were statistically analyzed in a similar manner to the stainless steel. Two sample t tests were used to compare the difference between nitinol archwire dimension induced torque and are presented in Table 6. Table 7 relates t scores and probabilities from 2 sample t test scores for different bracket torques on the central and lateral incisors.

Figure 17. Archwire Induced Torque Compared to Cross Sectional Area of The Stainless Steel Archwire on the Central Incisor.

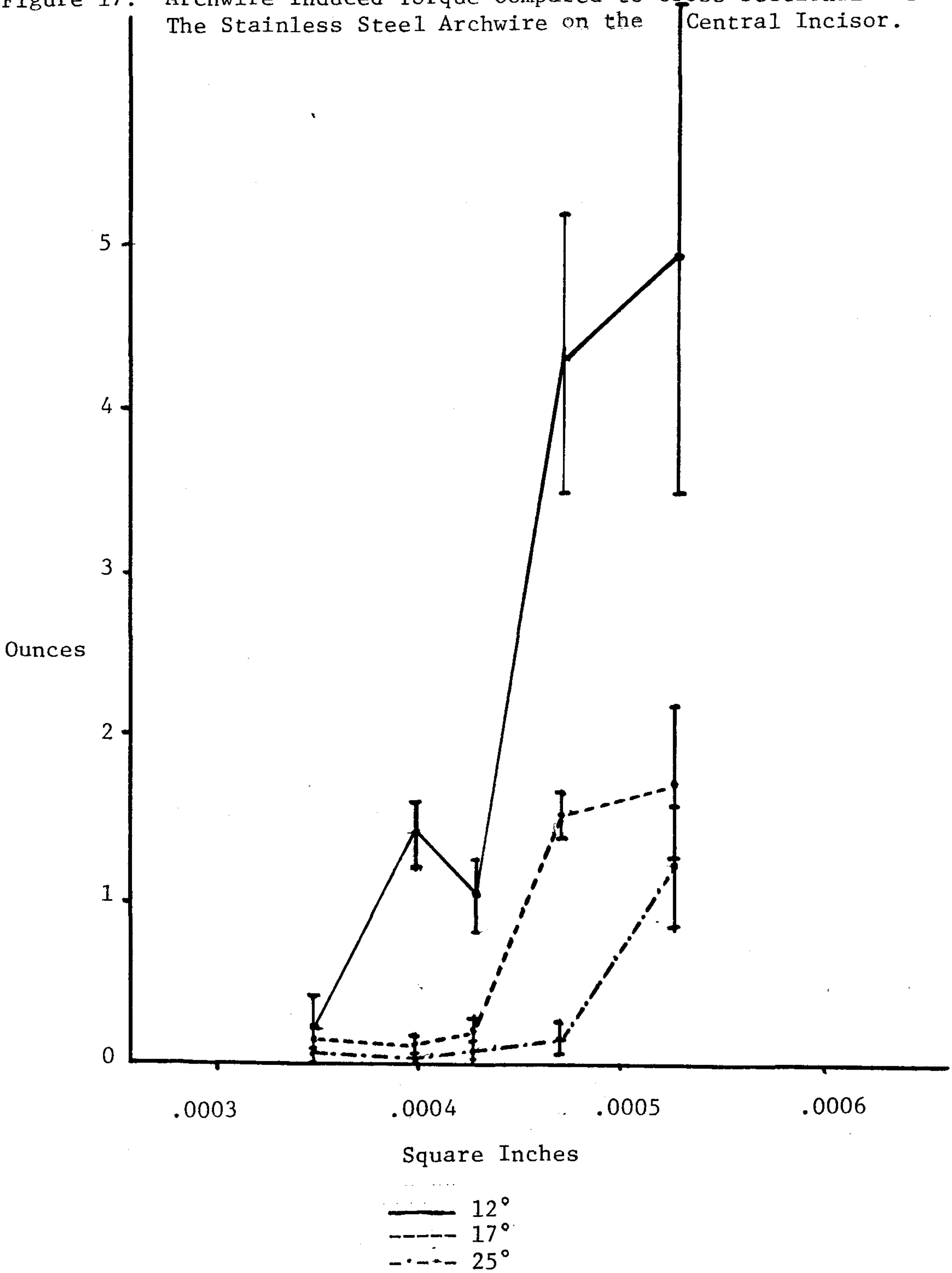


Figure 18. Archwire Induced Torque Compared to Cross Sectional Area of the Stainless Steel Archwire on the Lateral Incisor.

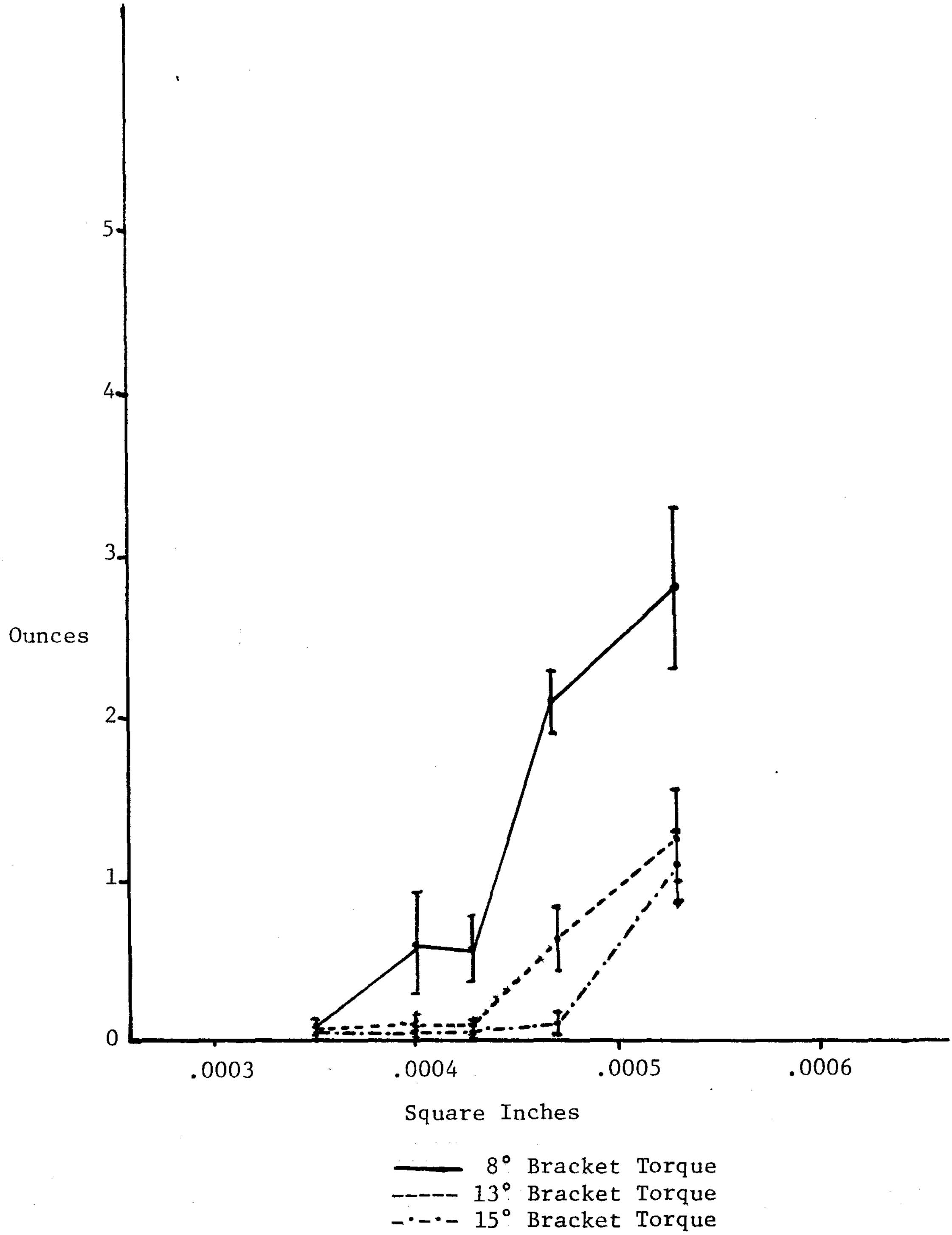


Table 4. Results of t Test on Stainless Steel Archwire Dimension Changes for Specific Bracket Angulations on Central and Lateral Incisors.

		.016 x .022 vs .017 x .025	.017 x .025 vs .018 x .022	.018 x .022 vs .019 x .026	.019 x .026 vs .021 x .025
Central Incisor	12°	.7919 P>.10	-1.47 P>.10	-2.28 .05>P>.02	-8.85 P<.01
	17°	.6590 P>.10	-1.70 P>.10	-13.66 P<.01	-4.01 P<.01
	25°	10.16 P<.01	-4.46 P<.01	-10.74 P<.01	1.16 P>.10
Lateral Incisor	8°	-2.52 P.05>P>.02	3.60 P<.01	-.3784 P>.10	-.9645 P>.10
	13°	-1.49 P>.10	1.13 P>.10	-11.32 P<.01	-4.23 P<.01
	15°	-6.77 P<.01	.56 P>.10	-12.55 P<.01	-3.98 P<.01

Table 5. Results of t Test on Bracket Angulation Changes for Specific Stainless Steel Archwire Dimensions on Central and Lateral Incisors.

Stainless Steel	12° vs 17°	17° vs 25°	8° vs 13°	13° vs 15°
.016 x .022	-2.70 .02>P>.01	-1.82 .10>P>.05	-2.14 .05>P>.02	-.1035 P>.10
.017 x .025	-.2215 P>.10	-10.90 P<.01	1.37 P<.10	-2.89 P>.01
.018 x .022	.431 P>.10	-18.65 P<.01	-2.01 .10>P>.05	-6.24 P>.01
.019 x .025	-13.35 P<.01	-12.28 P<.01	-9.76 P<.01	-15.25 P>.01
.021 x .025	-2.57 .02>P>.01	-6.36 P<.01	-1.38 P>.10	-8.17 P>.01

Table 6. Results of t Test on Bracket Torque Angulation Changes for Specific Nitinol Archwire Dimensions on Central and Lateral Incisors.

	1		2	
	12° vs 17°	17° vs 25°	8° vs 13°	13° vs 15°
.016 x .022	.10 $P>.10$	-1.31 $P>.10$	.48 $P>.10$	-1.06 $P>.10$
.017 x .025	5.25 $P<.01$	-9.39 $P<.01$	-1.23 $P>.10$	-9.14 $P<.01$
.019 x .025	1.44 $P>.10$	-8.80 $P<.01$	-2.58 $.02>P>.01$	-19.86 $P<.01$

Table 7. Results of t Test on Nitinol Archwire Dimension Changes for Specific Bracket Torque Angulations on Central and Lateral Incisors.

		.016 x .022 vs .017 x .025	.017 x .025 vs .019 x .025
1	12°	-6.03 $P<.01$	+2.96 $P<.01$
	17°	-.86 $P>.10$	-.07 $P>.10$
	25°	-6.95 $P<.01$	-1.15 $P>.10$
2	8°	-1.20 $P>.10$	.16 $P>.10$
	13°	-.52 $P>.10$	-1.83 $.10>P>.05$
	15°	-5.32 $P<.01$	-2.67 $.02>P>.01$

CHAPTER V

DISCUSSION

A common three-dimensional problem in orthodontics involves torquing the upper anterior teeth. Torque, or lingual rotation of maxillary incisor roots was needed for several reasons according to Jarabek (1963). Roots are positioned where the forces of occlusion coincide with the long axis of the teeth, providing for better overbite stability, incisal guidence and preventing a "rabbited appearance". The forces applied to the teeth are especially important in this movement. Efficient forces are said to move teeth satisfactorily without undue tissue disruption and patient discomfort. Storey and Smith (1952), Storey (1953), Reitan (1950) and Jarabek (1963) discussed the importance of optimal forces in moving teeth orthodontically.

Brian Lee (1975) attempted to determine biological forces for directional tooth movement. He felt a value of 200 grams/sq. cm. of "en face" root surface was necessary for tooth movement. Ricketts (1975) has reduced this value to 150 grams/sq. cm. for biologic efficiency in a more recent study.

The labial-lingual "en face" root surface of an average central and lateral incisor has been computed by Lee (1975). He calculated 0.5 sq. centimeters of central incisor root surface and 0.4 sq. centimeters of lateral incisor root surface. A biologically efficient force of

150 grams/sq. cm. according to Ricketts (1975) will require 75 grams (2.7) ounces of force for maxillary central incisor lingual root movement and 60 grams (2.1 ounces) of force for maxillary lateral incisor lingual root movement. Complicating factors occur when attempting to relate these forces to rectangular wire induced torque. The high load deflection of the edgewise torquing mechanism cause force values to drop significantly as the tooth rotates several degrees. Torque measurements are made in terms of force/distance. Forces applied to the root surface vary depending on the distance from the archwire.

To provide a more useful application of the data accumulated in this study, the forces applied to the teeth were considered as instantaneous. Torquing forces applied to the brackets distributed themselves over the entire "en face" root surface. No attempt was made to measure force values at a specific distance from the archwire. But rather the "en face" root surface could be divided into the torquing force determined to calculate an average force/root surface of the tooth being torqued.

Difficulty was encountered in the accurate placement of the brackets on the incisor teeth. Circumvention of this problem to some degree was accomplished by mounting the various torqued brackets on an .022 round stainless steel archwire. The brackets were then visually aligned in the center of the crowns. Eastman 910 adhesive was flowed between the mesh backing and labial surface of the incisor. By flowing the liquid adhesive behind the bracket mounted on the round wire it eliminated the adhesive thickness that was usually associated with other bonding materials. Consequently, the variable pressure as a result of different thickness was reduced significantly. Slight bracket mounting errors as small as 0.001 inch will cause forces to be placed on the teeth that normally would not be induced by the archwire. These errors could occur in the labial-lingual, occlusal-gingival or mesial-distal direction. The larger the archwire the less freedom of bracket mounting error and the more chance for extraneous force development.

Another problem encountered involved inserting the archwire the same way during the experiment. Reproducibility was arduous. To minimize this problem, the midlines marked on the preformed archwires were checked for accuracy and matched visually to the dentiform midline. However, it was noticed that with the large rectangular wires and large bracket torques a significant amount of friction was elicited in the buccal segments in response to the anterior torque. This friction caused the archwire to be held back to a greater or lesser extent and varied the expressed anterior torque. To decrease this variable, the entire arch was lubricated with WD40 oil and vibrated manually. However, the friction factor which was necessary for torque with a rectangular wire could not be entirely eliminated. The results of the heaviest archwires were more variable due to this problem.

The forces produced by the stainless steel archwires were statistically analyzed and sampled. A paired t test was used to determine differences between archwires and bracket torques.

The results of the .016 x .022 stainless steel archwires are displayed in Figure 9. This small dimensioned archwire in an .022 x .028 slot had a large degree of rotational freedom. The archwire must rotate significantly before engaging the walls of the bracket. However, a significant difference was found between 12° and 17° ($.02 > P > .01$) of bracket torque on the central incisor, and 8° and 13° ($.05 > P > .02$) on the lateral incisor. This finding was believed to be a result of slight discrepency in bracket mounting. The forces induced by the .016 x .022 archwire were extremely small and the slightest interbracket discrepency caused a force to be placed on the incisors. There was no significant difference between 17° and 25° on the central incisors and 13° and 15° on the lateral incisors.

The .017 x .025 stainless steel archwire torquing forces are depicted in Figure 10. The force varied on the central incisors from a mean of .05 ounce with 12° of torque to a mean of 1.0 ounce with 25° of torque. The lateral incisor torque force varied from a mean of .047 ounce with 13° of torque to a mean of .57 ounce with 15° of bracket torque. In Figure 10 the rapid increase in force between the 13° and 15° of lateral incisor bracket torque can be noted. There was a significant difference between these two bracket torque forces ($P < .01$). The central incisor torque force exhibited a similar reaction between 17° and 25° of bracket torque ($P < .01$). The torquing force increased from a mean of .15 ounce in the 17° bracket to a mean of 1.0 ounce in on the 25° bracket. This data indicated the use of a .017 x .025 stainless steel archwire required greater bracket torque angulations than 13° on the lateral incisor and 17° on the central incisor before the effective torque became apparent on the incisors. Bracket torque angulations smaller than this will be ineffective due to the rotational freedom of the .017 x .025 archwire in the .022 x .028 bracket slot.

The .018 x .022 stainless steel archwire torquing forces are displayed in Figure 11. The forces varied on the central incisors from a mean of .07 ounce with 17° of torque, to a mean 1.43 ounce with 25° of bracket torque. In Figure 4 the rapid increase in force between 13° and 15° on the lateral incisor can be seen. There was a significant difference between the force produced by the two brackets ($P<.01$). The central incisor exhibited a similar increase in torque force between 17° and 25° of bracket torque ($P<.01$). The results of .018 x .022 archwire were very similar to those achieved by a .017 x .025 archwire. Table 4 showed a statistically significant difference existed between the two wires only in the highest bracket torque of 25° on the central incisors. Similarly, bracket torques were above 13° on the lateral incisor and 17° on the central incisor before the effect of torque became apparent.

The .019 x .025 stainless steel archwire torquing forces are depicted graphically in Figure 12. The forces varied on the central incisors from a mean of .16 ounce with 12° of bracket torque to a mean of 4.31 ounces with 25° of bracket torque. The lateral incisor torquing force varied from a mean of .11 ounce with 8° of bracket torque to 2.06 ounces with 15° of bracket torque. Figure 5 displays the increase in force applied to the incisors by the .019 x .025 archwire as bracket torque increased. Significant increases in force on the lateral incisors were noted between 8° and 13° of bracket torque, ($P<.01$) and also between 13° and 15° ($P<.01$). The central incisor reacted in a similar manner as the lateral incisor with a significant increase in force between 12° and 17° ($P<.01$) and 17° and 25° ($P<.01$). Using the .019 x .025 archwire, torquing force developed at smaller bracket torques than the previously tested smaller diameter archwires. With 13° of bracket torque on the lateral incisor, a .019 x .025 archwire placed a mean of .75 ounce as opposed to the .016 x .022, .017 x .025, or .018 x .022 which exhibited less then .10 ounce. Using 17° of bracket torque on a central incisor, a .019 x .025 archwire had a mean of 1.06 ounce of torquing force as opposed to the .016 x .022, .017 x .025 and .018 x .022 archwires which placed less than .2 ounce on the central incisor.

The above data indicated, that with a .019 x .025 archwire, the bracket torque combination of 13° on the lateral incisor and 17° on the central incisor will develop forces over .75 ounces for torquing of the incisors. When one examined the largest of bracket torque combinations of 15° on the lateral incisor and 25° on the central incisor the torquing force rose significantly over the 13° and 17° bracket torque combination ($P<.01$). These highest bracket torque angulations used with an .019 x .025 archwire developed a mean of 4.3 ounces of force on the central incisor and 2.06 ounces on the lateral incisor.

The largest tested archwire was the .021 x .025. Results of the .021 x .025 stainless steel archwire torquing forces are depicted graphically in Figure 13. The forces varied on the central incisors from a mean of 1.23 ounces with 12° of bracket torque to a mean of 4.95 ounces with 25° of bracket torque. The lateral incisor torquing force varied from a mean of 1.06 ounces with 8° of bracket torque to a mean of 2.78 ounces with 15° of bracket torque. Figure 13 depicts the increase in torquing force applied to the incisors as the bracket torque increases with a .021 x .025 archwire. A significant increase in force on the lateral incisors were noted between 13° and 15° ($P<.01$) of bracket torque, however there was no significant difference between 8° and 13°. This may in part be due to the large variance found in using the largest of archwires resulting from friction in the buccal segments.

The central incisor developed significant increase in force between 12° and 17° ($.02<P<.01$) and 17° and 25° ($P<.01$). Using the .021 x .025 archwire a larger torquing force developed at smaller bracket torques than any of the previously tested smaller diameter archwires. The .021 x .025 archwire placed 1.23 ounces of force on the central incisor with 12° of bracket torque, whereas the largest mean torquing force placed by the previously used smaller dimensional archwires was .16 ounces and on the lateral incisor with 8° of bracket torque the mean force was 1.06 ounces. The largest generated mean force from the previously used smaller diameter archwires tested was .11 ounce. The data showed forces generated with a .021 x .025 stainless steel archwire will be greater than one ounce even in the smallest bracket torques tested of 8° on the lateral incisor and 12° on the central incisor.

Nitinol archwires were tested in the three sizes of rectangular maxillary preformed archwires. The forces produced were statistically analyzed and graphed. A paired t test was used to determine differences between archwires and bracket torques.

The results of the .016 x .022 nitinol are displayed graphically in Figure 14. Archwires of this dimension in a .022 x .028 slot had a large degree of rotational freedom. The archwire must rotate significantly before engaging the walls of the bracket. Both central and lateral incisor showed no statistical difference on the various bracket torques. The light forces recorded could be attributed to a discrepency in bracket mounting and differences in placement of archwires. The amount of torque force placed on the incisors by an .016 x .022 nitinol archwire in an .022 x .028 slot was considered insignificant for torquing teeth.

The .017 x .025 nitinol archwire torquing forces are compared to bracket torque in Figure 15. The force varied on the central incisors from a mean of .06 ounce with 17° of bracket torque to .59 ounce with a

25° of bracket torque. No significant difference was found between 12° and 17° of bracket torque. However, a significant difference existed between 17° and 25° of central incisor bracket torque. The lateral incisor torquing force varied from a mean of .04 ounce with 13° of bracket torque to a mean of .24 ounce of torquing force with 15° of bracket torque. The forces developed on the lateral incisors are considered extremely light. The .017 x .025 nitinol archwire was considered insufficient for torquing incisors, knowing that the largest mean force developed for 25° of bracket torque was only 0.59 ounce.

The .019 x .025 nitinol archwire results were displayed graphically in Figure 16. Forces developed by this largest dimension of nitinol archwire were measured at .06 ounce of torquing force on the central incisor with 17° of bracket torque, and .65 ounce of torquing force on the central incisor with 25° of bracket torque. The lateral incisor torquing force ranged from a mean of .02 ounce with 13° of bracket torque to a mean of .29 ounce with 15° of bracket torque. In Figure 16, an increase in torquing force occurred between 13° and 15° of bracket torque on the lateral incisor ($P < .01$) and between 17° and 25° on the central incisor ($P < .01$). However, an unexpected significant decrease in force occurred between 8° and 13° of bracket torque on the lateral incisor ($.02 > P > .01$). Again, when forces are extremely light, as in this situation, a slight bracket height discrepency may induce a significant difference in force applied to the tooth. This also showed the extreme sensitivity of the strain guages in picking up the smallest force.

Comparison of the nitinol and stainless steel archwires involved examining the forces delivered by similar dimensioned archwires in the .022 x .028 bracket slot. Both the .016 x .022 stainless steel and nitinol archwires were considered inadequate for torquing maxillary incisors. The force generated by the .016 x .022 archwires of either composition was less than a mean of .28 ounce. The rotational freedom of a .016 x .022 archwire in the .022 x .028 slot was such that it was inadequate for torque on this dimension.

Stainless steel and nitinol of the .017 x .025 dimension differed in the largest of bracket torques. The stainless steel archwire on the central incisor with 25° of bracket torque placed 1.01 ounces of torquing force, while the nitinol archwire placed a lesser .59 ounce of force. The 17° bracket torque on the central incisor with the .019 x .025 stainless steel archwire placed .15 ounce of torquing force, while the nitinol archwire produced even less with .06 ounce of force. The lateral incisor with 15° of bracket torque received .54 ounce of torquing force from the stainless steel archwire, while the nitinol produced .24 ounce with the .017 x .025 archwires. The lesser bracket torques produced very light forces considered insignificant for both stainless steel and nitinol.

Comparisons of the .019 x .025 archwires showed the stainless steel to apply greater forces than the nitinol archwires. With 12° of torque on the central incisor, the stainless steel and nitinol archwires torquing force for the three bracket torques of 12°, 17° and 25° were plotted in Figure 17. The graphic representation showed each of the bracket torques produced larger forces with larger cross sectioned areas of the archwire. Lateral incisor torque force reacted in a similar manner on the three tested bracket torques of 8°, 13° and 15°. A larger variation in applied force was noted as the cross sectioned area of the archwire increased. This was thought due to the great amount of friction in the buccal segments with the heavy rectangular wires, and its effect on the torque by binding at slightly different anterio-posterior positions.

Comparisons of the .018 x .022 to .017 to .025 in Figures 16 and 17 for both central and lateral incisors with the highest bracket torques showed that a slightly larger mean force was delivered by the .018 x .022 archwire. However, the .017 x .025 has a larger cross sectional diameter. Speculating as to the cause of this, one may consider the .018 x .022 arch as closer to a square shape than .017 x .025. This may allow the .018 x .022 archwire to greater resist the torsion placed on it and deliver a greater torque force, or the rotational freedom for the .018 x .022 archwire may be less.

Thurow (1972) describes .001 inch freedom of the wire in the slot as giving 2° to 4° of rotational freedom. A difference of .002 inch brings the torque freedom to well over 5°. The data accumulated in this study indicated that significant torque developed from an .021 x .025 archwire with a .001 inch freedom of the wire using a bracket torque of 8°. However a .019 x .025 archwire with .003 inch freedom of the wire in the slot produced only .16 ounce of force on the 8° torqued bracket. The .019 x .025 archwire had probably more than 8° of rotational freedom and therefore applied an insignificant torque force on this bracket.

Shrody (1974) described the effect of anterior torque on the buccal segments. He concluded the buccal segment reaction to anterior lingual root torque was a complex system consisting of a combination of counter torque, buccolingual linear, and occlusal gingival linear forces. The results of this study indicated torquing forces applied to the incisors was complex and the forces generated depended upon many factors. Errors in bracket mounting, and archwire placement will affect the force induced on the dentition. The effect of anterior torque distributed itself over the entire dentition, and the distribution of the forces generated a greater or lesser effect on the adjacent teeth. Torquing forces were found to increase with larger archwire dimension and bracket torque. The composition of the archwire affected the torque in its ability to resist torsion. Nitinol was found to generate less of a torquing force than stainless steel.

Based on the results of this study the torque combinations chosen by the clinician will depend on several factors. One factor would be the size of the final finishing archwire. Also the amount of force desired and the degree of root torque attempted. Because of the large variation in orthodontic treatment techniques, magnitude at force application, and patient variations, each practioner will have to determine the combination which best suits the needs of his specific patient.

Many questions remain unanswered and it is anticipated future research will explore these areas. The entire complex interchange of forces applied by an archwire engaged in the edgewise appliance needs to be described more accurately. Force systems from other bracket slot sizes should be determined. The effect of variations in manufactured slot size and archwire size also need to be studied. The interactions of the many variables will affect the forces produced by the archwire. If the orthodontist is to comprehend more fully the forces applied through the edgewise appliance these questions need to be answered.

CHAPTER VI

SUMMARY AND CONCLUSIONS

A technique was developed for measuring the torquing force applied to the maxillary incisors with rectangular wire in the straight wire appliance. A simulated maxillary dentition was constructed using strain guages attached to the four incisor teeth. The strains induced by the forces of the archwire were converted to ounces. Resultant torquing forces for each size archwire were displayed graphically to better visualize the effect of bracket torque on the force produced. Five different Unitek maxillary preformed stainless steel archwires (.016 x .022, .017 x .025, .018 x .022, .019 x .025, .021 x .025) and three different nitinol archwires (.016 x .022, .017 x .025, .019 x .025) were inserted in three different anterior bracket torque angulation combinations (8° and 12°, 13° and 17°, and 15° and 25°). Each archwire size was inserted five times into the maximum depth of the brackets. The results were analyzed statistically to determine the effect of changes in bracket torques and archwire dimension on the torquing force produced.

The simulated maxillary dentition was developed to represent an average maxillary arch. The results achieved were under ideal conditions, with the incisors in exact alignment. It would be rare to encounter a similar situation clinically. A more realistic situation would include the incisors in asymmetrical relation to one another, with greater bracket discrepancies. Forces produced would also depend on the morphology of the crowns, roots and arch form. To obtain the maximum usable data, an average maxillary arch form was constructed.

The results of this study have shown that a rectangular archwire placed in a bracket slot will produce a net force on the teeth. The magnitude of force applied depends upon the size, composition and shape of the archwire in addition to bracket torque, and variations in the brackets three dimensional position on the tooth. This study attempted to eliminate the variables of archwire shape and bracket position, to measure force applied by varying composition, size and bracket torque. Measurements of the torquing force applied to the teeth are summarized as follows:

1. Stainless steel .016 x .022 archwires deliver insignificant torque forces to the incisors due to the great degree of rotational freedom in the bracket.

2. Stainless steel .017 x .025 and .018 x .022 archwires react similarly and require bracket torques above 13° on the lateral incisor nad 17° on the central before torquing forces developed in this study.

3. Stainless steel .019 x .025 archwires induce torquing forces at bracket torques below 13° on the lateral incisor and 17° on the central incisor with the .021 x .025 archwire producing torquing forces at even smaller bracket angulations.

4. The magnitude of the force produced by the rectangular

archwire was a function of its cross sectional dimension and the bracket torque. The induced force rose rapidly with the largest archwires and greatest bracket torques.

5. The nitinol archwire tested induced less torque than the stainless steel of the same dimension. The greatest mean force produced by the largest of manufactured nitinol archwires (.019 x .025) was less than .66 ounce and far below optimal levels.

Many questions remain unanswered and it is anticipated that further research will provide a better understanding of the torque force. Because of the variation in treatment, goals, forces, and mechanics, each practicioner must determine which bracket torque combinations and archwire sizes will best suit his needs for better appliance control and patient treatment.

CHAPTER VII

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The thesis is therefore accepted in partial fulfillment of the requirements for the degree of Master of Science.

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